Physiological Responses

SLL MasterClass 2016 / 17

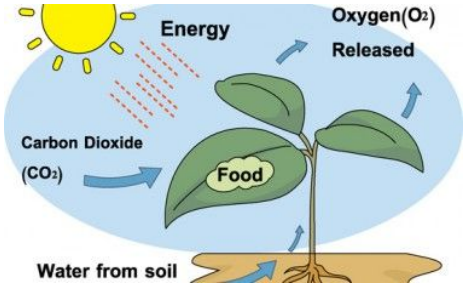
Chris Wilkes

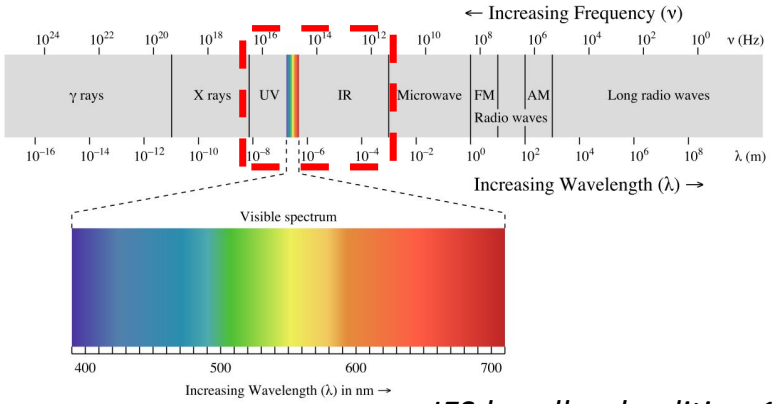
Photobiology

Humans, animals and plants have complex physiological responses to the daily and seasonal variations in solar radiation under which they evolved.

Photobiology is the study of these responses to optical radiation in the ultraviolet (UV), visible, and infrared (IR) portions of the electromagnetic spectrum.

Photobiological responses result from chemical and physical changes produced by the absorption of radiation by specific molecules in the living organism





IES handbook edition 10 Page 3.1

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There are lots of examples of lighting effecting nature….

While the subject of the all of our talks today is “Human Responses to Light”

Lets take a quick look at the natural world around us….

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There are lots of examples of lighting effecting nature….

Page 80 LG6;
A4.4 – Birds and Flight

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There are lots of examples of lighting effecting nature….

Page 80-81 LG6;
A4.4 – Bats

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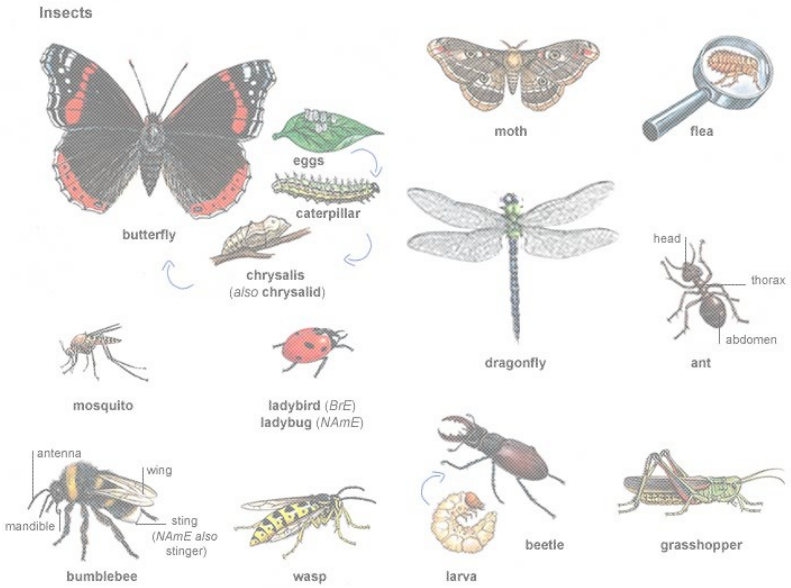
There are lots of examples of lighting effecting nature….

Page 82 LG6;
A4.4 – Amphibians

There are lots of examples of lighting effecting nature….

Page 82 LG6;
A4.11 – Invertebrates/Insects



Effect of optical Radiation – *Wide and Varied*

What effects are there that light can have on humans?

Effect of optical Radiation – *Causing harm or damage*

Locat or Process	Ultraviolet (100nm – 400nm)	Visible and near-IR (380nm – 1400nm)	IR (Over 1400nm)
Skin	Erythema (delayed)	Burns	Burns
	Carcinogensis	Erythema (Immediate)	Erythema (Immediate)
	Aging		
	Drug Photosensitivity		
	Melanogensis		
	Melanoma (Postulated)		
Eye - Cornea	Photoconjunctivitis		
	Photokeratitis		
Eye - Lens	Cataracts (immediate and delayed)	Near-IR cataracts	IR cataracts
	Coloration Sclerosis		
Eye – Retina	Retinal Changes	Thermal lesion	
		Shock lesion	
		Photochemical lesion	
		Macular degeneration (postulated)	

Effect of optical Radiation – *Beneficial*

Locat or Process	Ultraviolet (100nm – 400nm)	Visible and near-IR (380nm – 1400nm)	IR (Over 1400nm)
Phototherapy	Psoriasis	Retinal detachment	
	Herpes simplex	Diabetic retinopathy	
	Dentistry	Hyperbilirubinemia	
	Treatment of vitiligo, eczyma	Glaucoma	
	Photochemotherpy	Removal of port wine birth marks and tattoos	
		Surgery	
		Seasonal Affective Disorder	
		Jet Lag	
Non-theraputic	Vitamin D production	Biological rhythms	Radiant heating
	Protective pigmentation	Hormonal activity	
		Behaviour	
		Circadian rhythm set	

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2016 Human Physiological Responses to Light Meeting Report

July 19th, 2016

Washington, D.C.

Prepared For:

U.S. Department of Energy

Solid-State Lighting Program

Tulane University
Thomas Jefferson University
Lighting Research Center
University of California San Diego
Thomas Jefferson University
F.Lux Software LLC
Cree
Brigham and Women's Hospital
Lighting Science Group
Pacific Northwest National Laboratory
NEMA
Acuity Brands Lighting, Inc.
Philips Lighting Research
Johns Hopkins Bloomberg School of Public Health
University of Connecticut
University of Colorado Boulder
Stanford University School of Medicine

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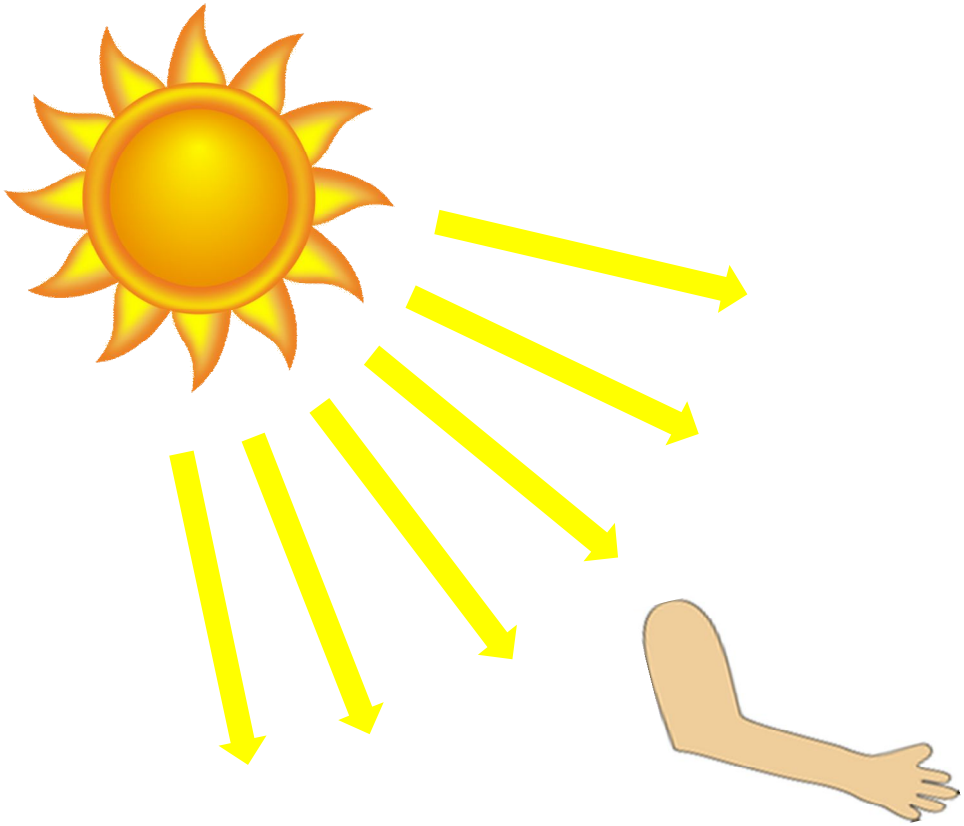
Example Summary

Vitamin D



UVB (280nm -315nm)

Transforms Cholesterol-containing body oils into pre-Vitamin D

Absorbed by body transformed into Vitamin-D then moved by blood around the body.

UV used for the treatment of various skin diseases such as Psoriasis and eczema

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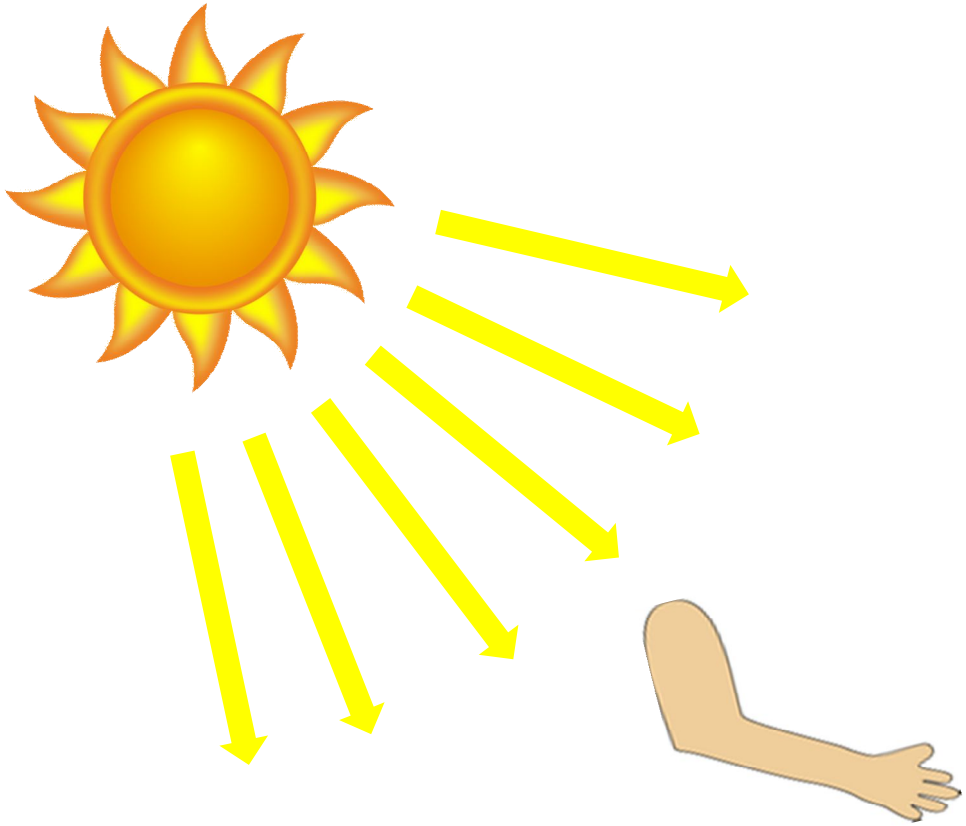
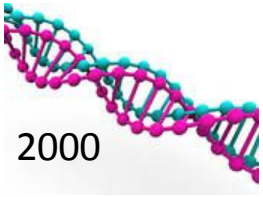
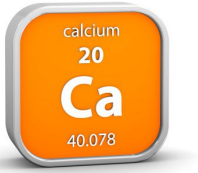




10 mins a day



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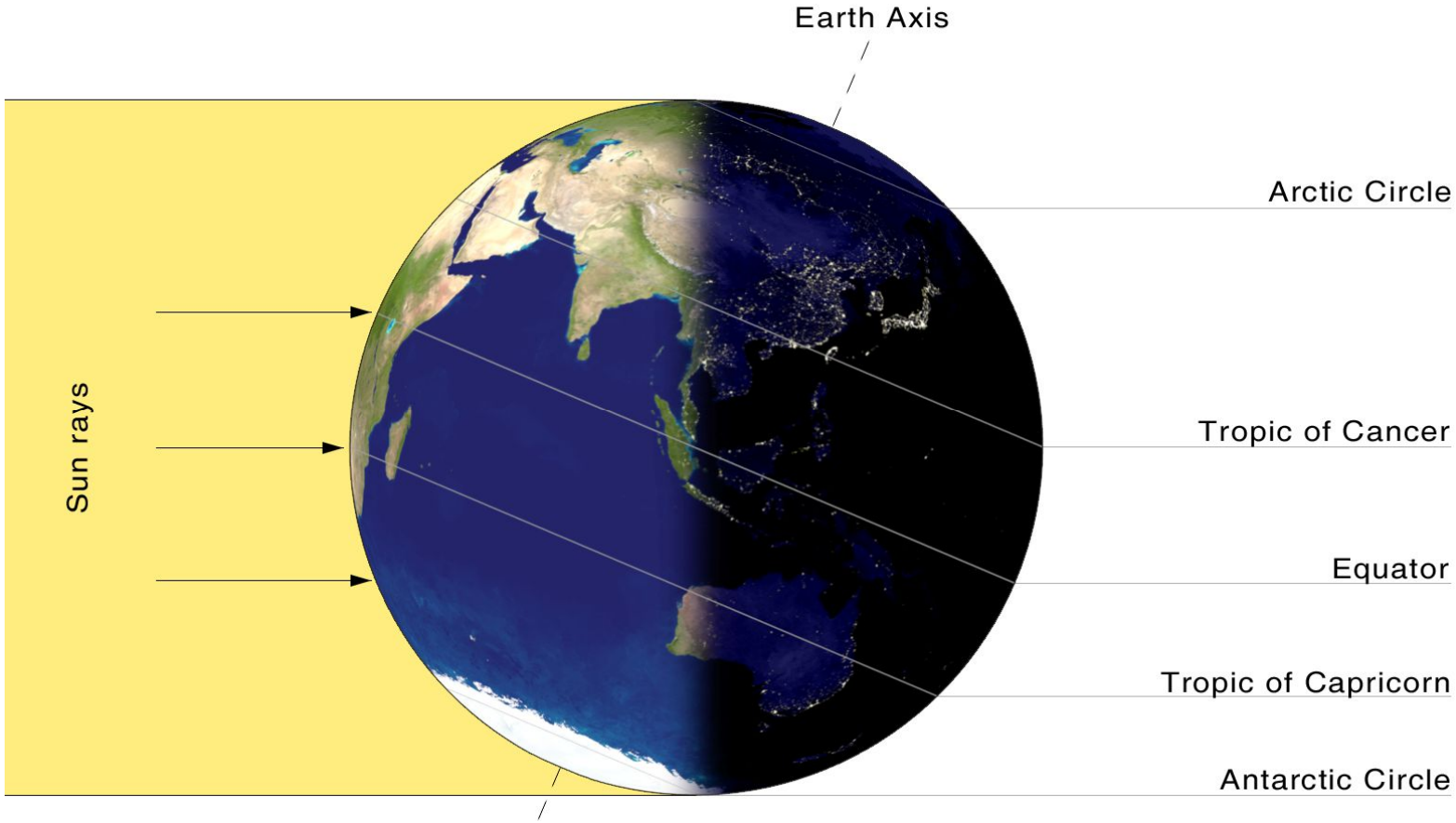
Example Summary

Seasonal Affective Disorder


Earth Axis
Arctic Circle
Sun rays
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle

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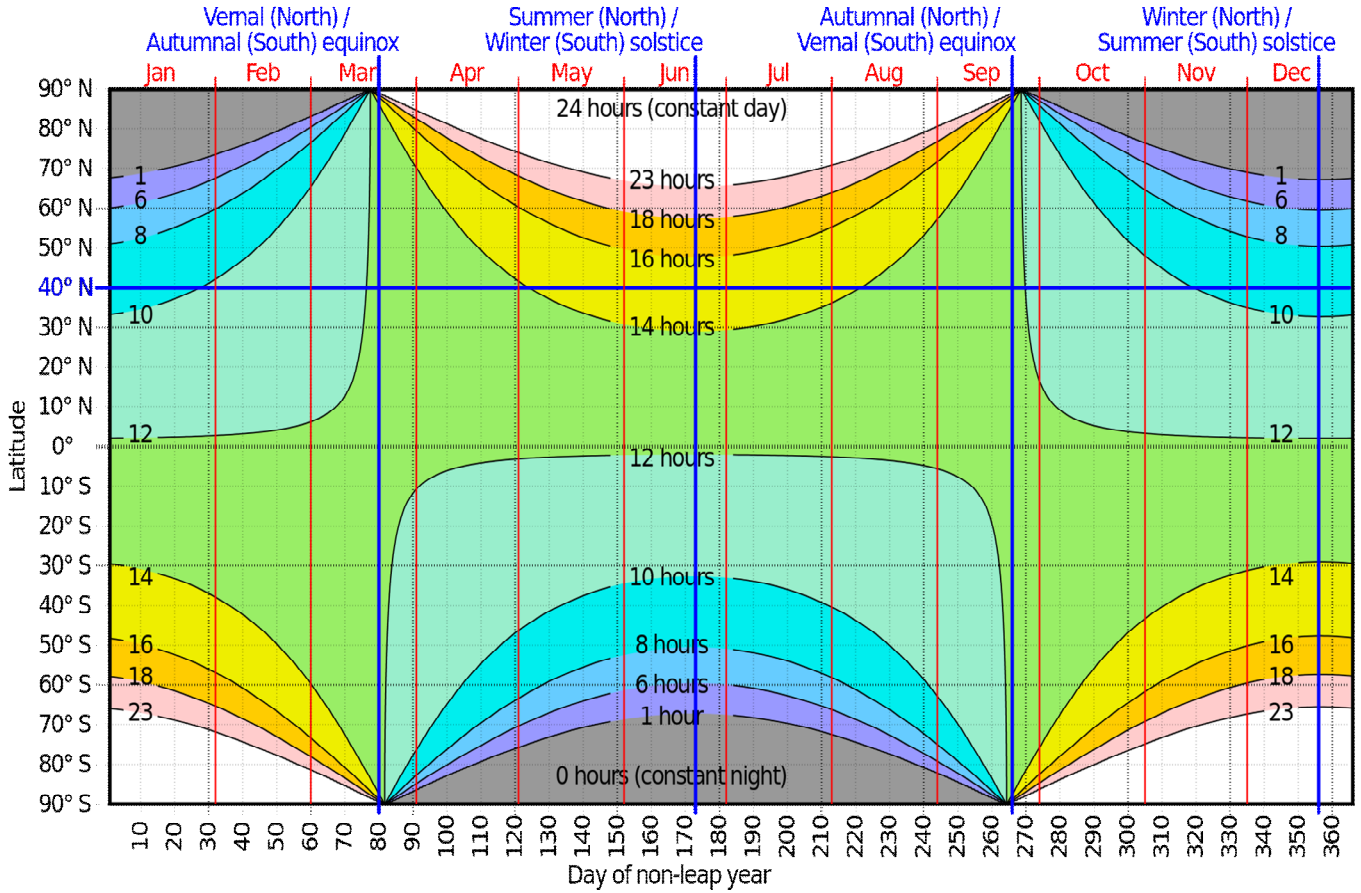

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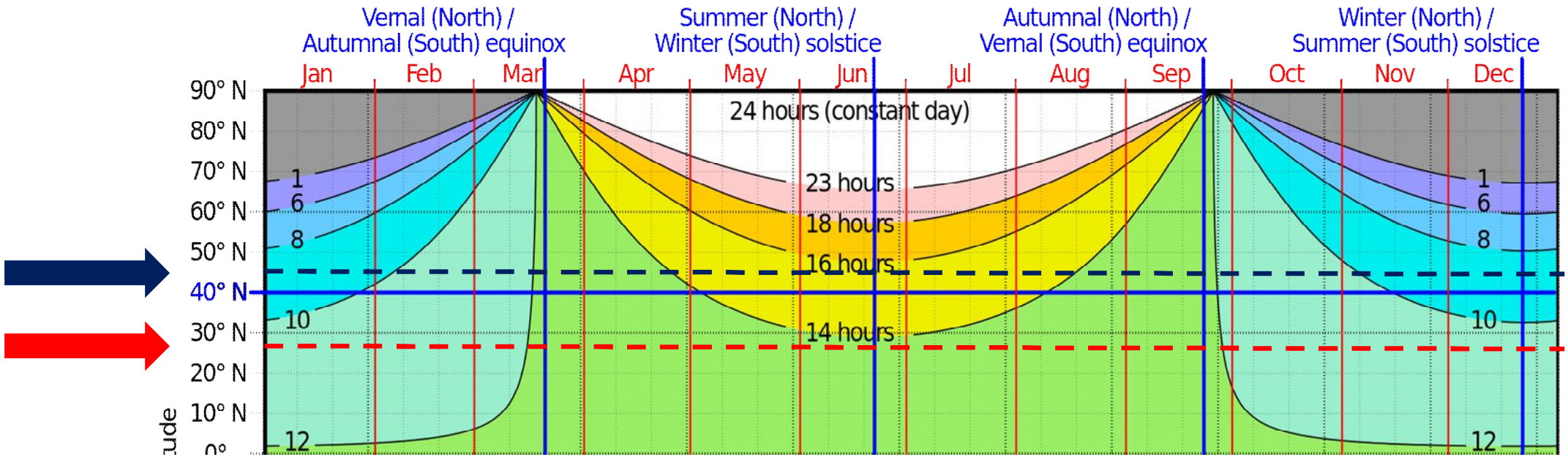
Florida - 2% of population - Latitude 27.7ºN

New Hampshire - 10% of population - Latitude 43.2ºN



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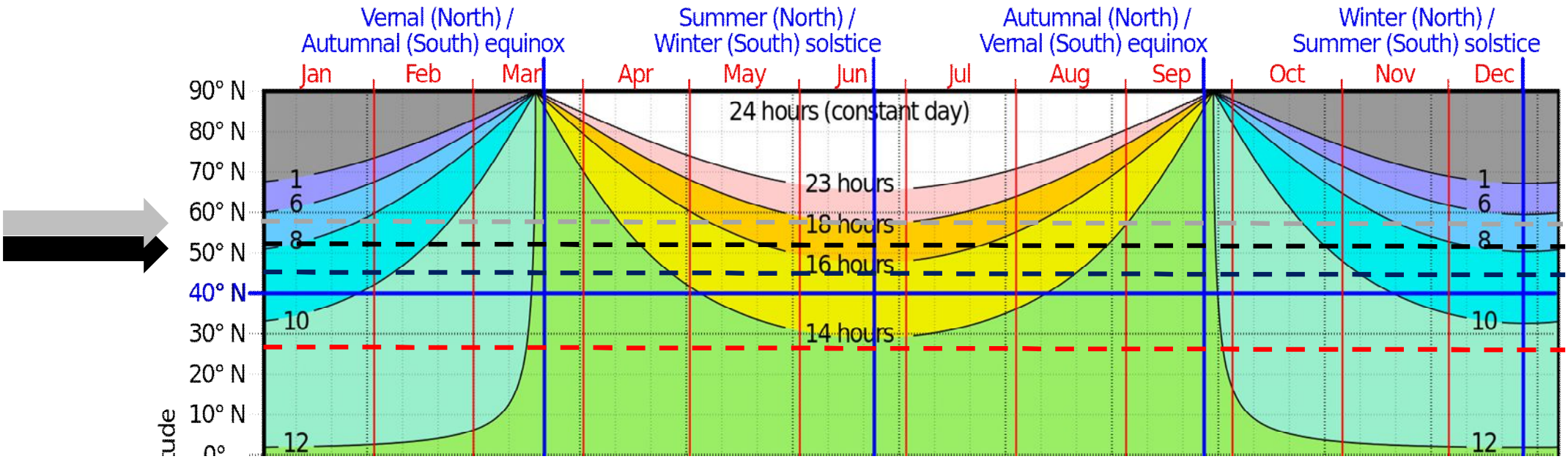
London 51.5ºN

Wick Scotland – 58.4ºN



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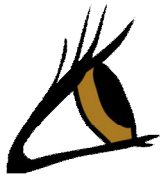
Good effects – Seasonal Affective Disorder

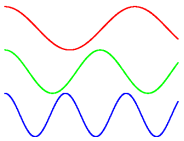
Image from : www.sad-lighthire.co.uk

30 mins – 4 hours

2,500 lux – 10,000 lux



Optical nerve



Shorter Wavelength

Human response to Visible light

Human response to Visible light

Human pupil….
Contraction and Dilation

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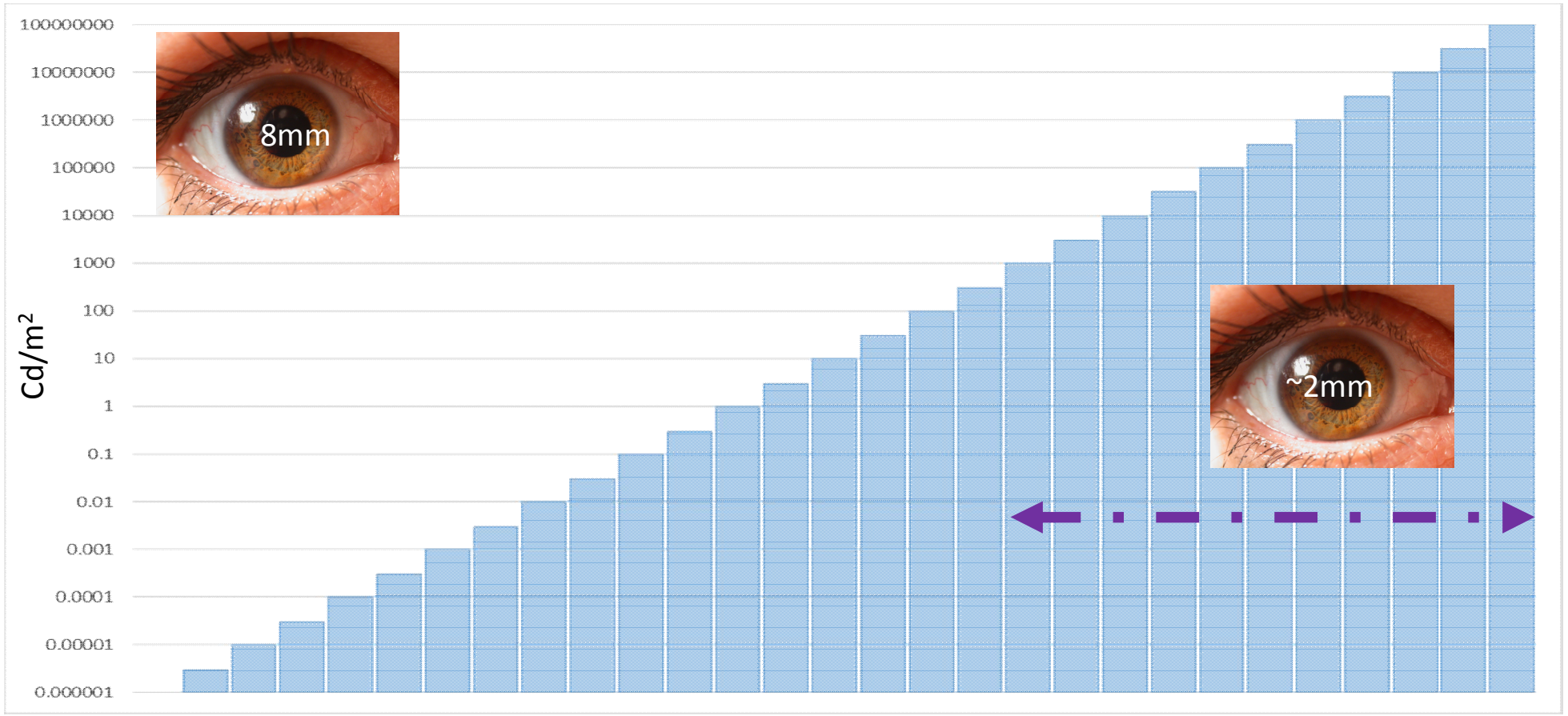
Human response to Visible light



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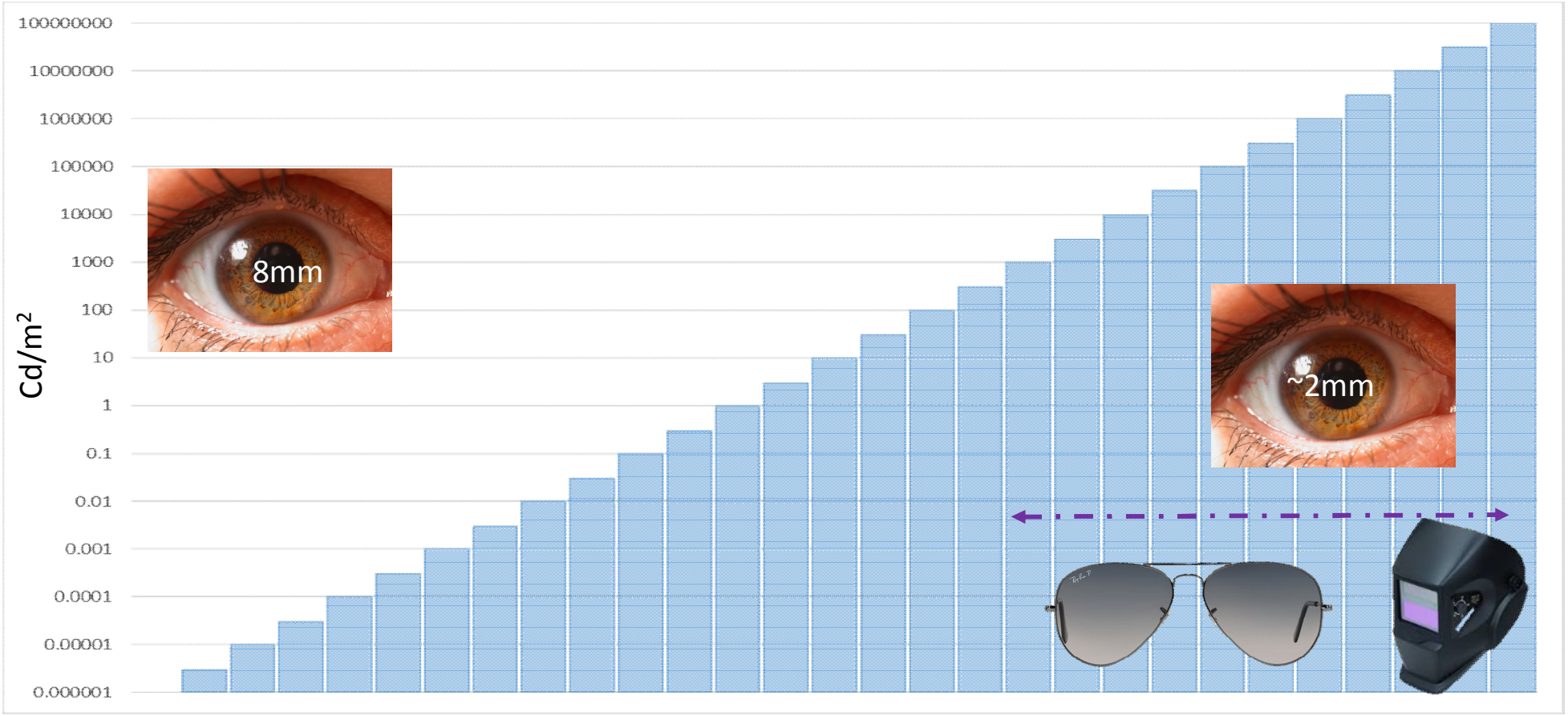
Vision Adaptation States

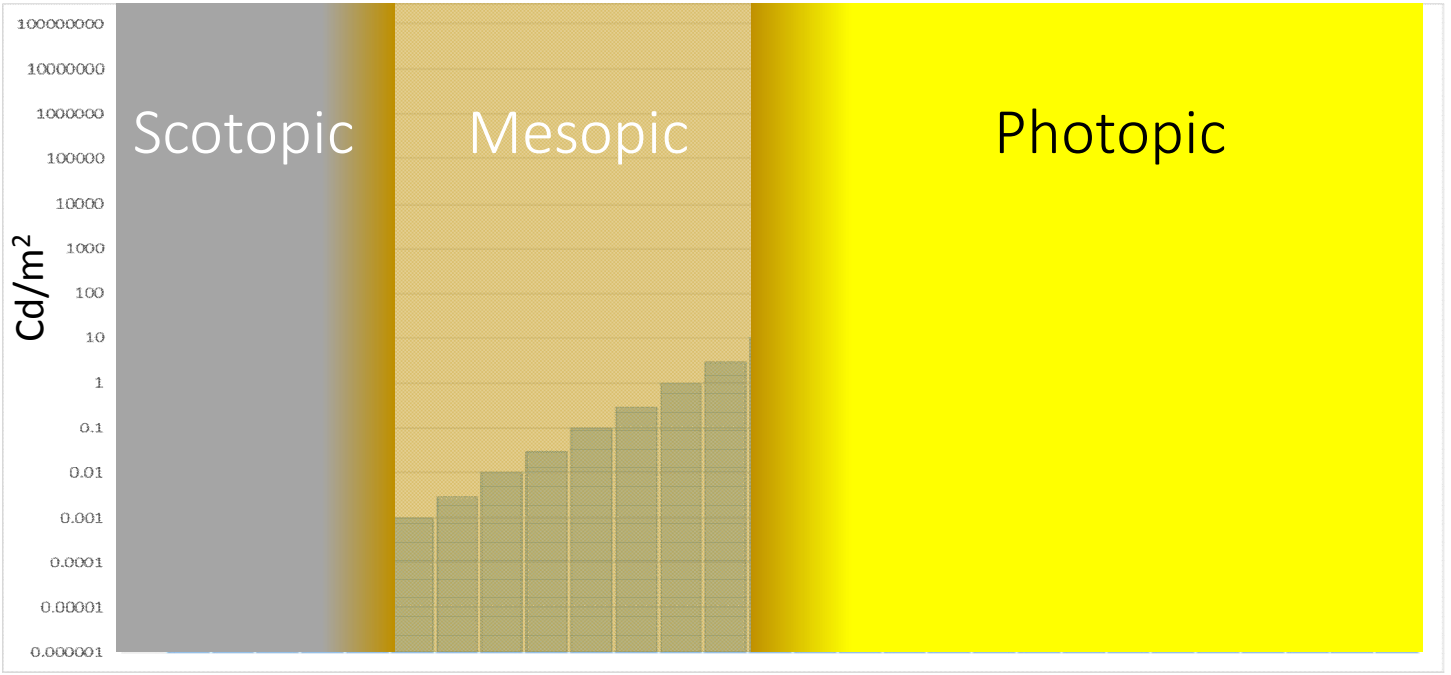


Human response to Visible light

Scotopic – “Night time Vision” – Mono chromatic – Lacking Detail

Photopic – “Day time Vision” – Lots of colour – Plenty of detail

Mesopic – Transition between the two….



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Human response to Visible light

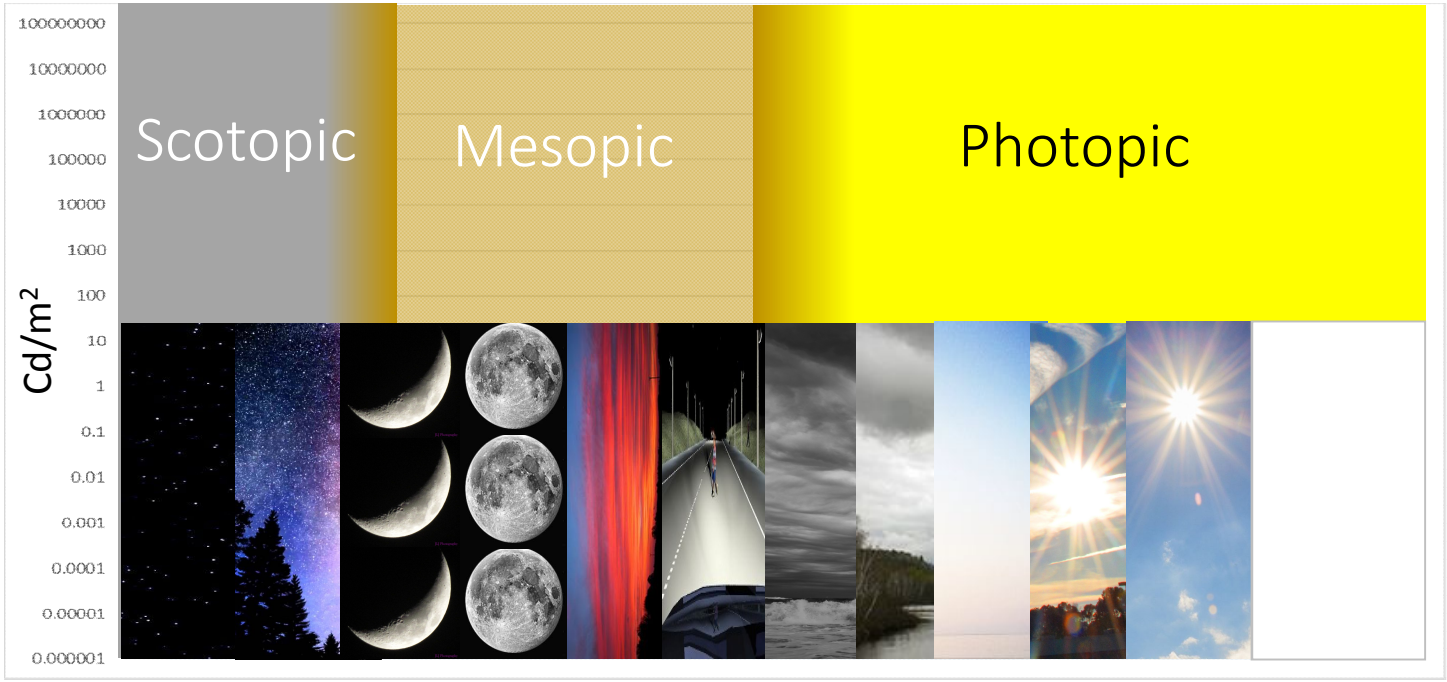
Moonless Clear Night Sky

Car Head lights

Sun at different time of day

Quarter Moon

Over cast skies



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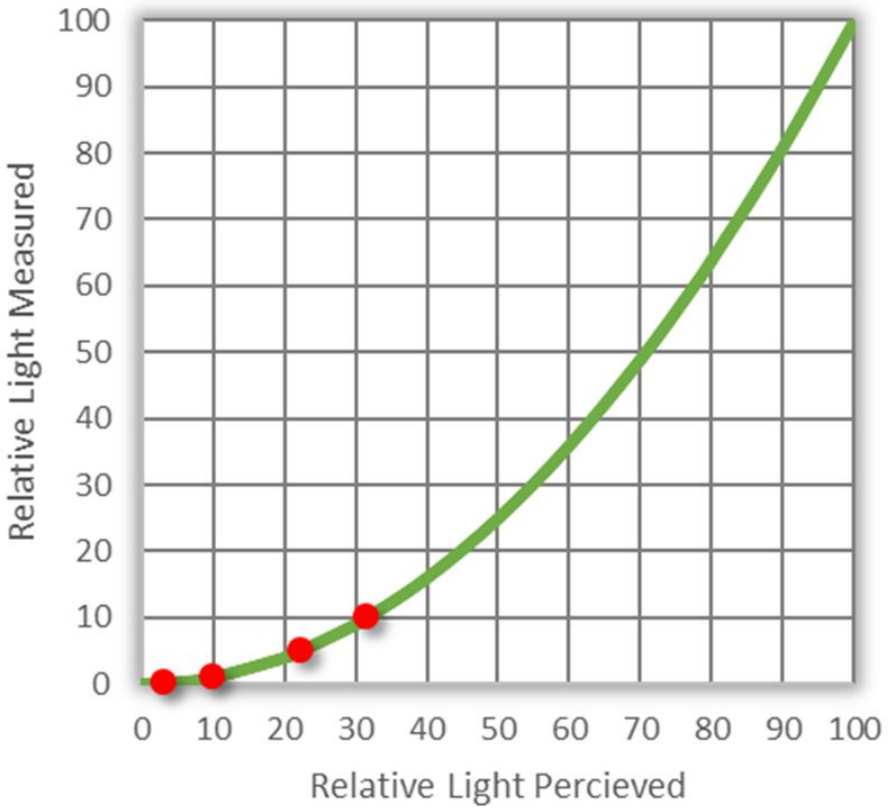
How do we perceive light…

Human response to Visible light

Starting in a lit space and dimming, our eye does not perceive the measured lux level….

Dim Level	Perceived Level
10%	32%
5%	22%
1%	10%
0.1%	3%



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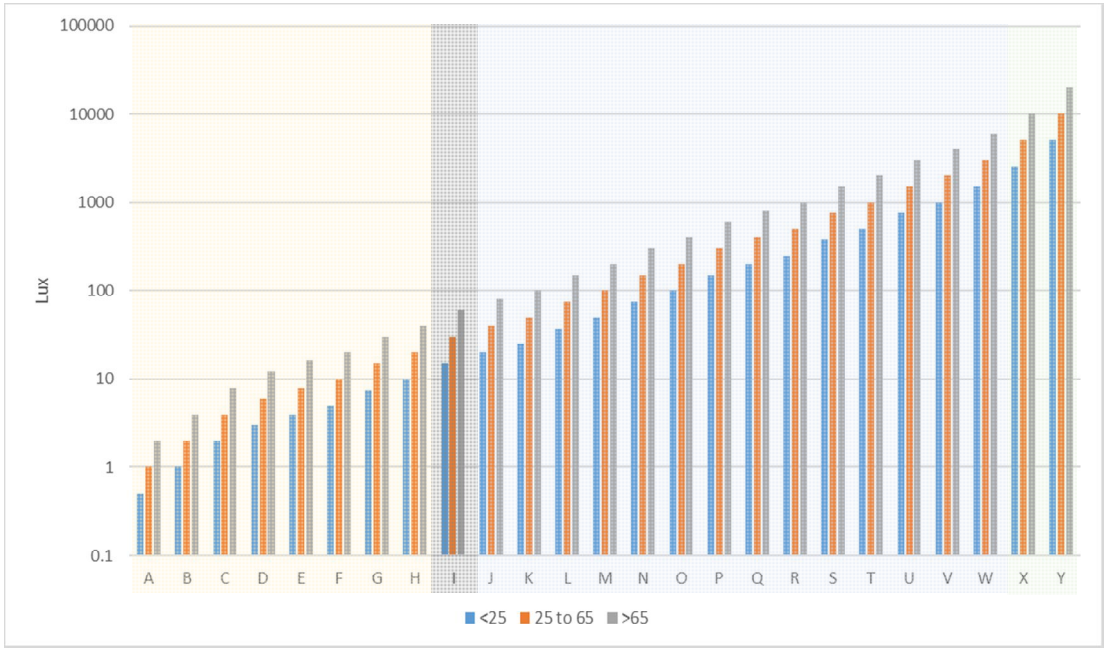
Age of viewer – how much affect?



<25	25-65	>65
1	x2	x4

Interior and EXTERIOR applications

Most outdoor lighting requirements

INTERIOR and EXTERIOR applications

Busy outdoor, indoor social

INTERIOR and exterior applications

Sports, healthcare, general indoor, commerce outdoor

INTERIOR applications

Some health care procedural situations

IESNA handbook 10th edition Page 4.33

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Colour of light – Orange or White

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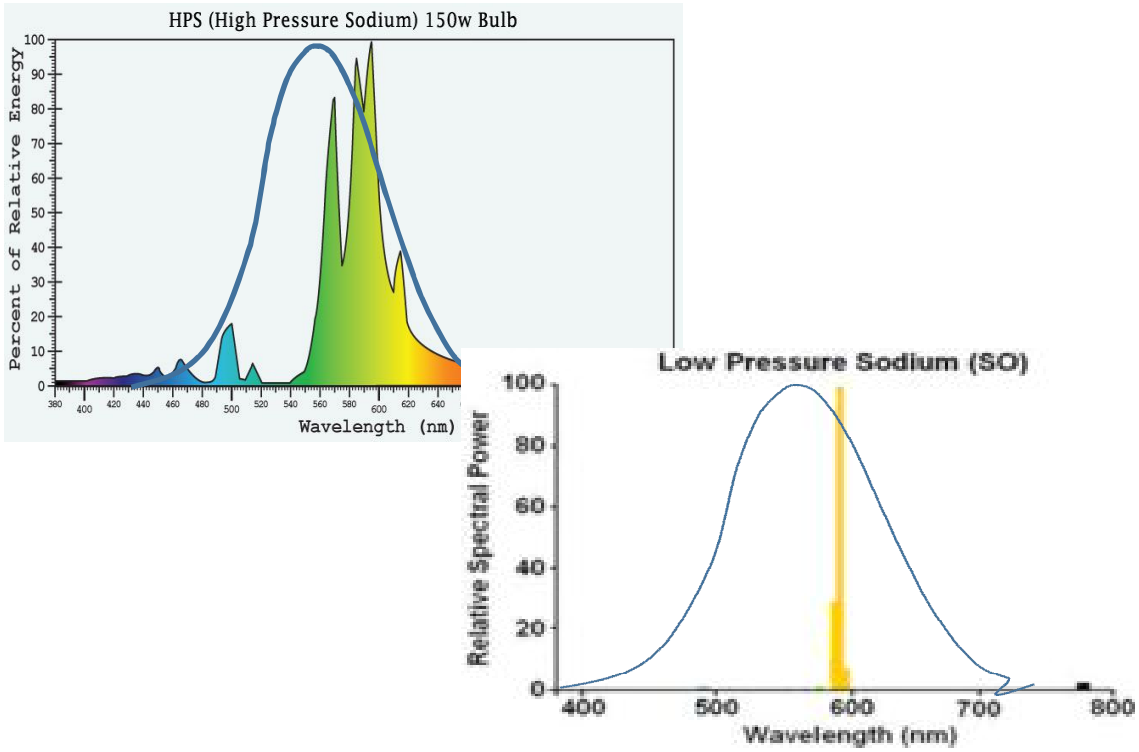
Human response to Visible light - Orange

- Vλ (Photopic) efficiency



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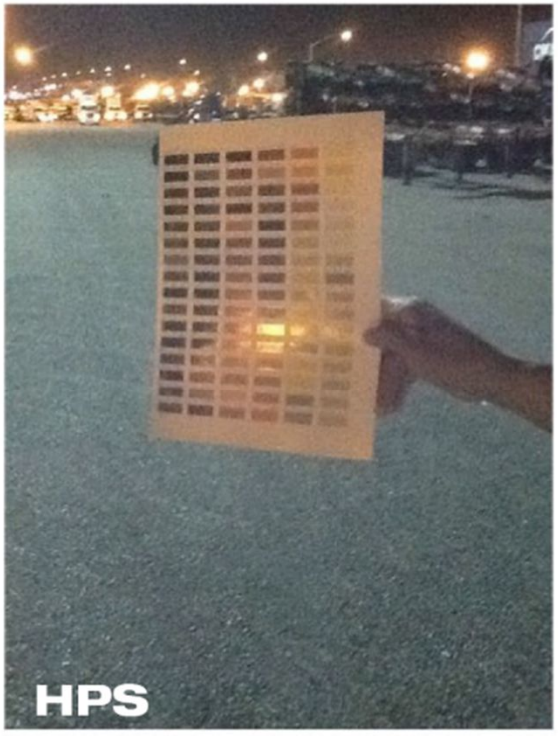
Human response to Visible light - Orange

Rubbish Colour Rendering…

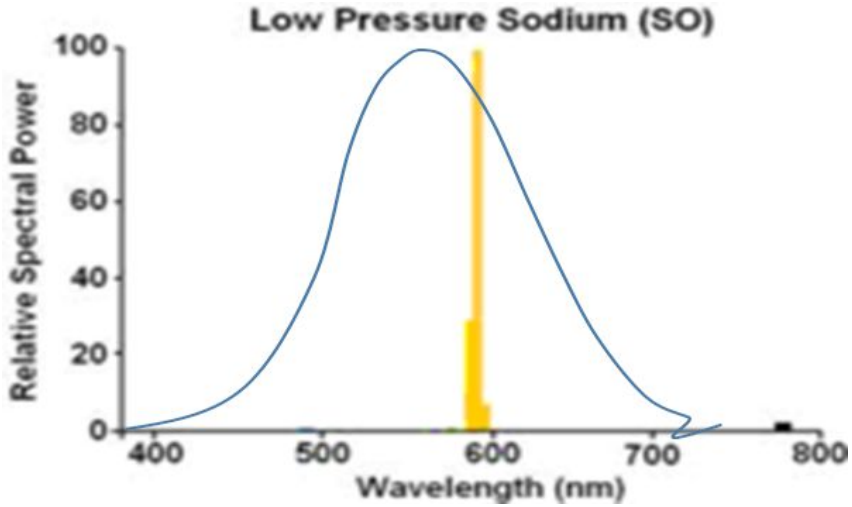


Foreground - HPS / Background - LED

Foreground - LED / Background - HPS

Human response to Visible light - Orange

Astronomers don’t hate it…



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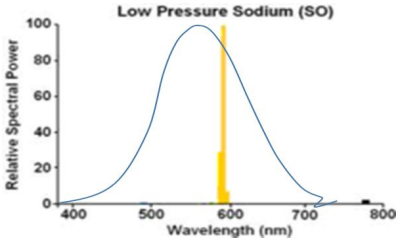
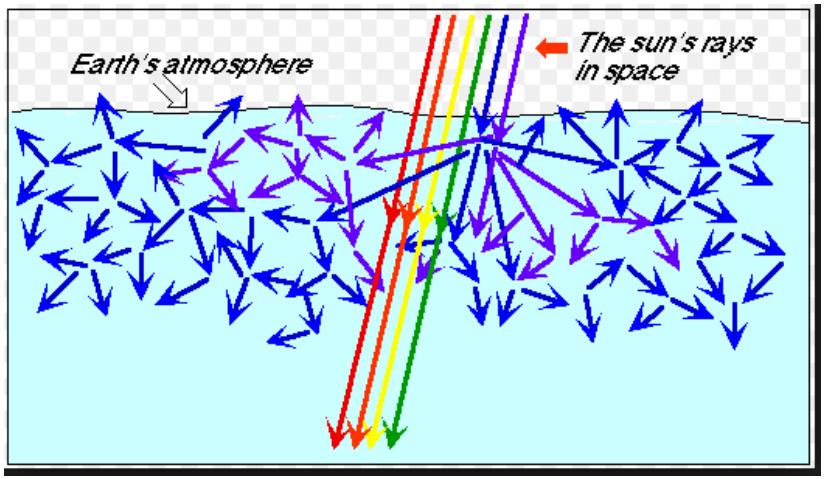
Human response to Visible light - Orange

The Sky is Blue…





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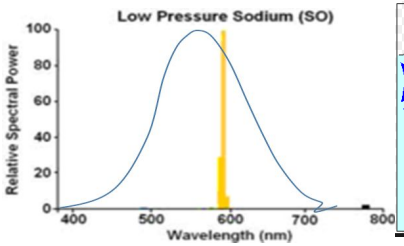
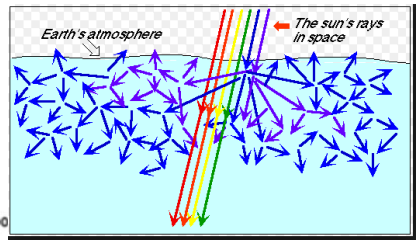
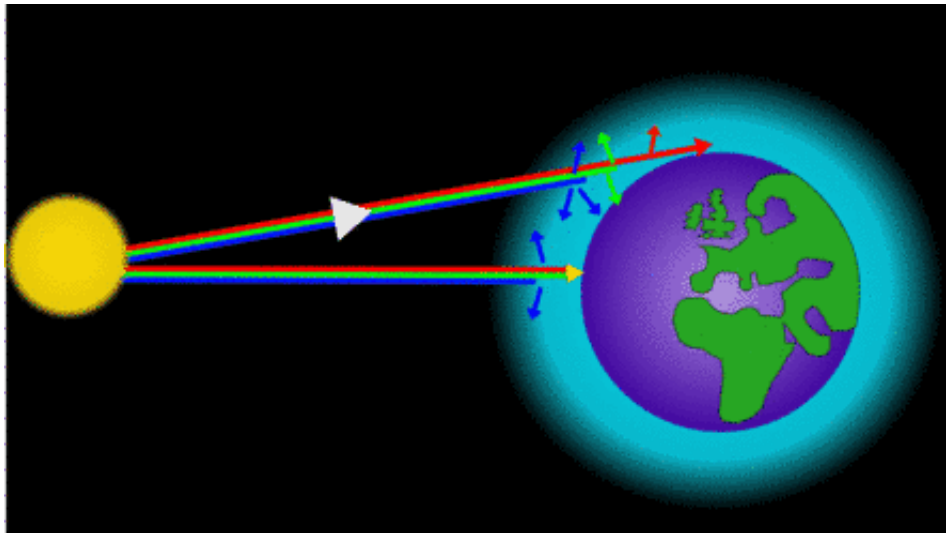
Human response to Visible light - Orange

The Sky is Blue…



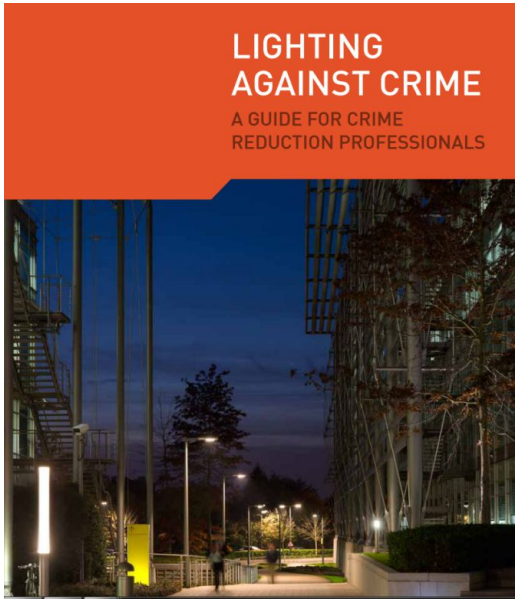




Human response to Visible light - White

We feel safer, and less crime is committed;

A good lighting system is one designed to distribute an appropriate amount of light evenly with Uniformity Values of between 0.25 and 0.40 using lamps with a rating of at least 60 on the Colour Rendering Index. Good lighting will use energy efficient lamps in suitable luminaries. These luminaries will be positioned to minimise any light pollution so as to provide a high quality system only when and where required.



www.securedbydesign.com

Human response to Visible light - White

Can use less power;

Table A.7 **Variation of maintained lighting level with S/P ratio of light source**

Values in lux

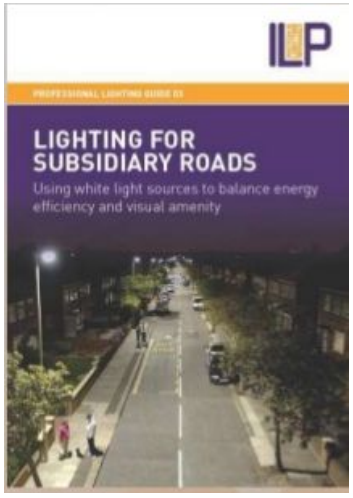
Lighting class	Benchmark (e.g. R_a < 60 or when S/P ratio of light source is not known or specified)		S/P ratio = 1.2 and $R_a \geq 60$ (e.g. some types of warm white lamp such as metal halide)		S/P ratio = 2 and $R_a \geq 60$ (e.g. some types of cool white compact fluorescent or LED)	
	$\bar{E}$	E_{min}	$\bar{E}$	E_{min}	$\bar{E}$	E_{min}
P1 or S1	15.0	3.0	13.4	2.7	12.3	2.5
P2 or S2	10.0	2.0	8.6	1.7	7.7	1.5
P3 or S3	7.5	1.5	6.3	1.3	5.5	1.1
P4 or S4	5.0	1.0	4.0	0.8	3.4	0.7
P5 or S5	3.0	0.6	2.2	0.4	1.8	0.4
P6 or S6	2.0	0.4	1.4	0.4	1.1	0.4

BS 5489-1:2013

BSI Standards Publication

Code of practice for the design of road lighting

Part 1: Lighting of roads and public amenity areas



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Public Health England

Protecting and improving the nation's health

The Society of Light and Lighting

CIBSE

CRCE-RDD 01-2016

Human responses to lighting based on LED lighting solutions

Commissioned by the Chartered Institution of Building Services Engineers and the Society of Light and Lighting

Public Health England

Protecting and improving the nation's health

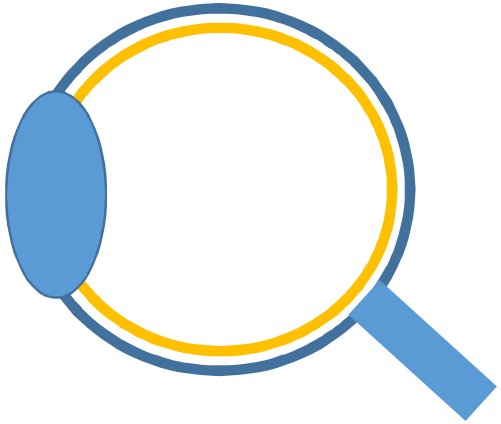
Protect and improve health and wellbeing, and reduce health inequalities.

PHE is an executive agency, sponsored by the Department of Health

This report concerns Human responses to lighting based on LED lighting solutions and has been produced by Public Health England (PHE) for the Chartered Institution of Building Services Engineers, CIBSE and the specialist professional body for lighting, the society of light and lighting (SLL)

Blue Light hazard

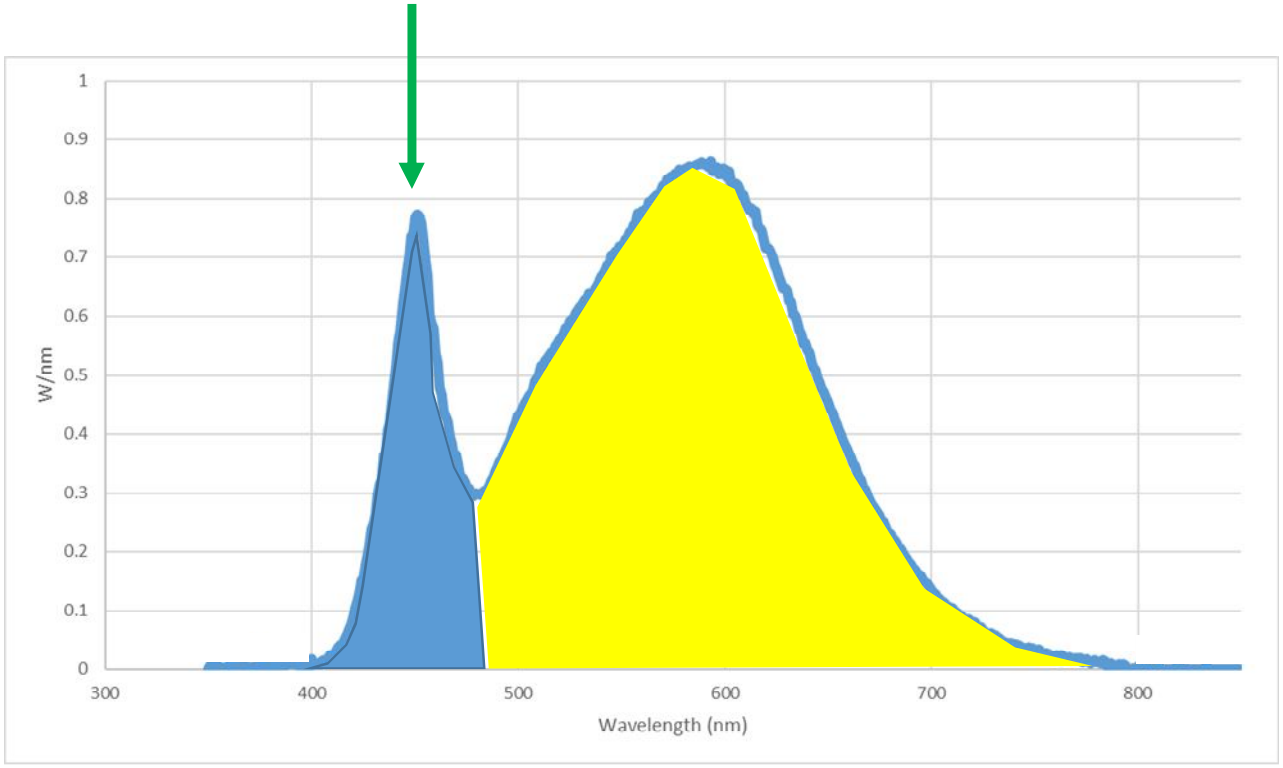
Blue light is known to be phototoxic for the retina.



The International Commission on Nonionizing Radiation Protection (ICNIRP) regularly reviews the biological evidence and publishes exposure guidelines.

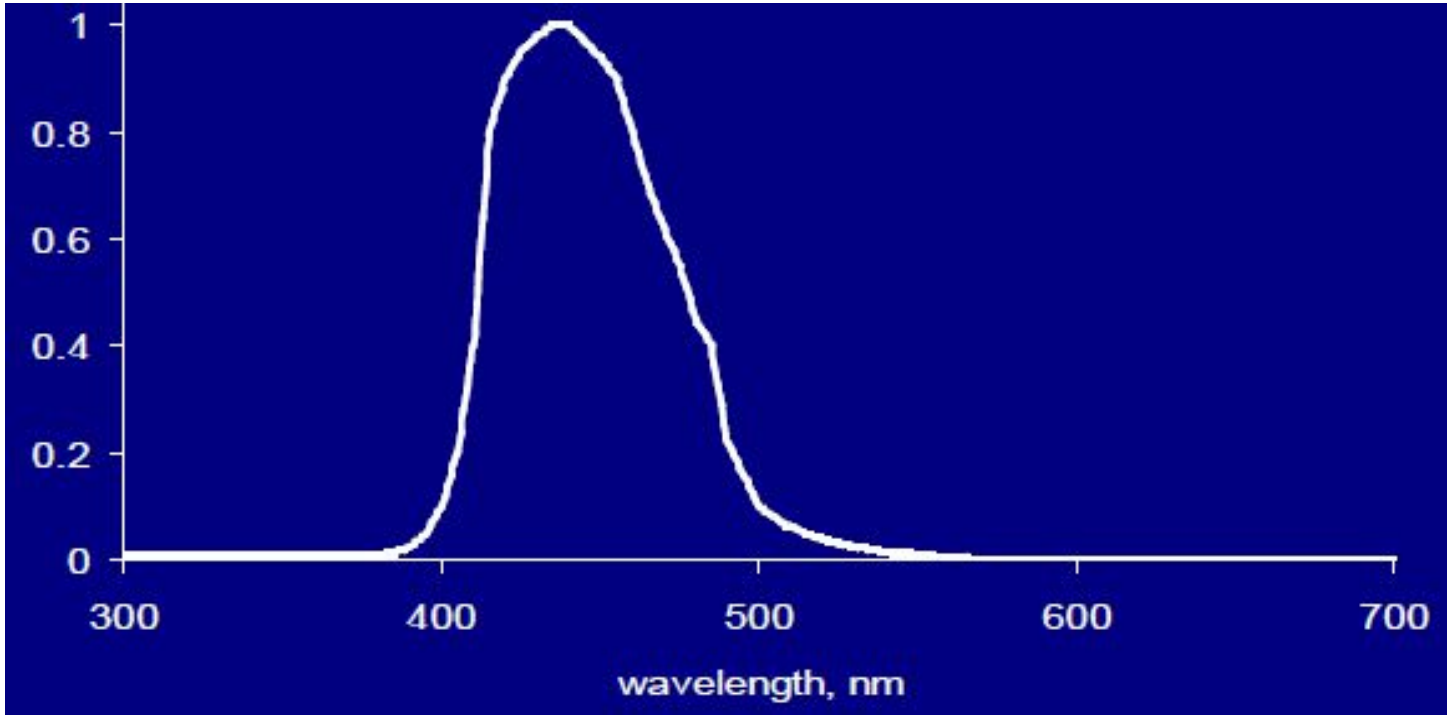
ICNIRP
INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION
www.icnirp.org

Blue Light hazard – why might LED be bad?



The blue LEDs used in street, office and domestic LED lighting generally emit at around 450 nm to 460 nm. For this reason, there are concerns that the guidelines may be exceeded……

Blue Light hazard – why might LED be bad?



Blue Hazard function

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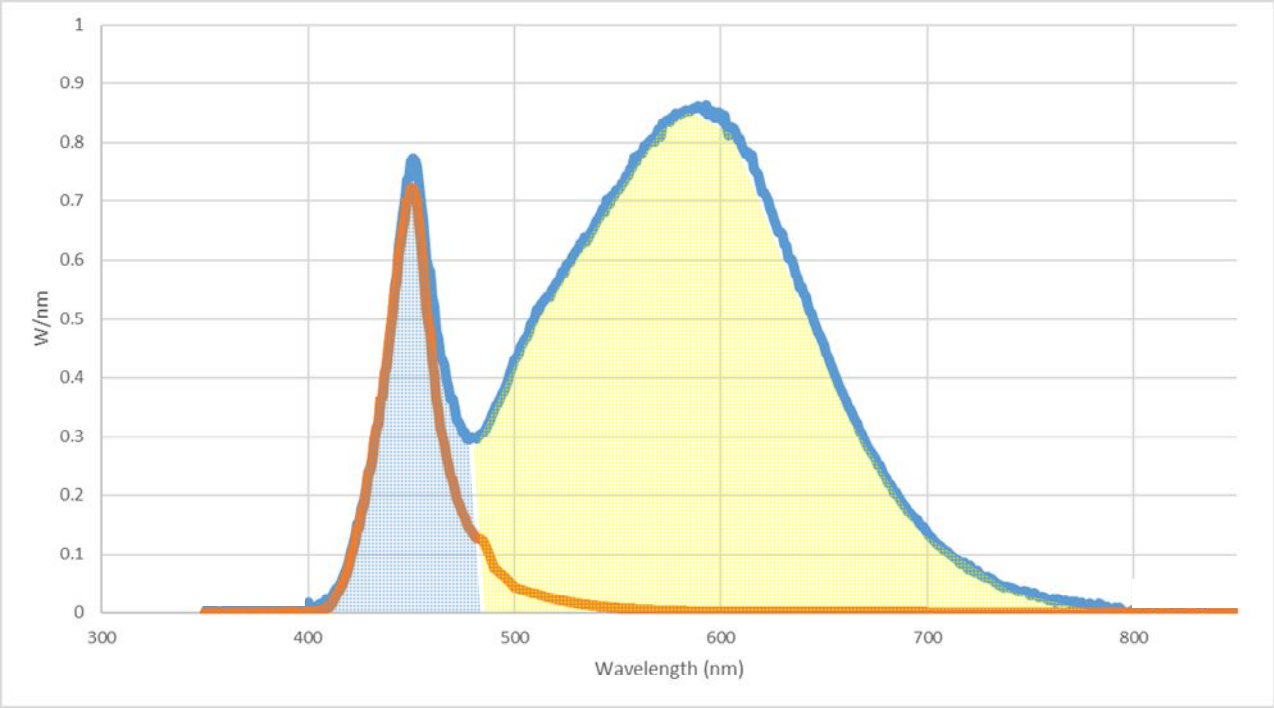
Blue Light hazard – why might LED be bad?



Weighted Irradiance
Blue Hazard function applied

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Blue Light Hazard – Ocular Safety

Public Health England

Protecting and improving the nation's health

The Society of Light and Lighting

CIBSE

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Human responses to lighting based on LED lighting solutions

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No UV

Negligible Infrared

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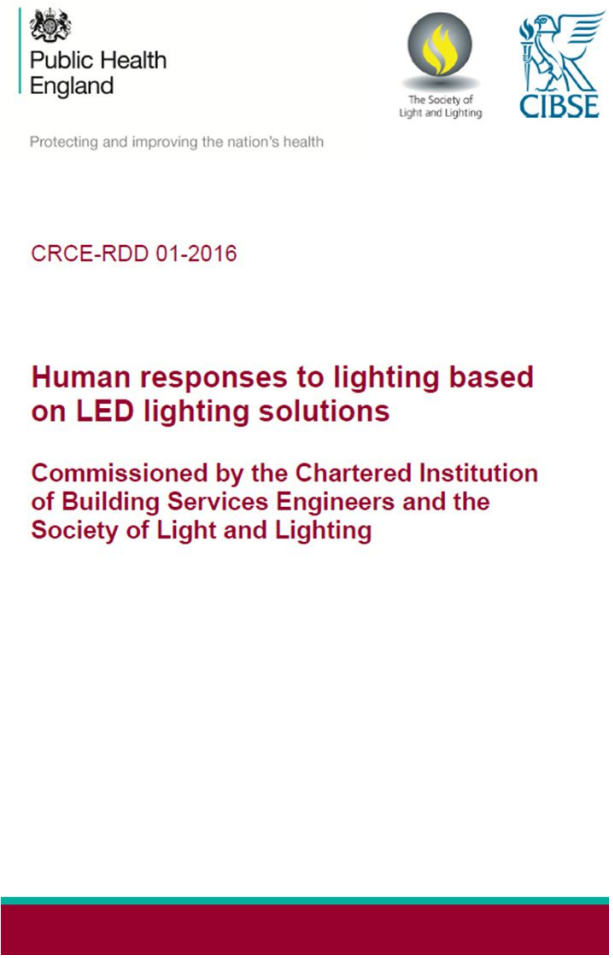
Blue Light Hazard – Ocular Safety



No UV

Negligible Infrared

LED fittings measured;
Not bright enough to cause retinal damage in normal use at reasonable distances.

Blue Light Hazard – Ocular Safety

Public Health England

Protecting and improving the nation's health

The Society of Light and Lighting

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What about at non-reasonable distances?

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What about at non-reasonable distances?

At a distance of **2 m**, reaching the exposure limit values for the Blue Light Hazard would require steady fixation for over **2½ hours**, based on conservative calculations.

ICNIRP
INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

Blue Light hazard – tablets, e-readers, phones?

LEDs are associated with tablets and e-readers, but the light exposures from e-readers are not necessarily equivalent in illuminance or spectrum to an LED for general lighting. News articles often appear relating to people's concerns about these devices and the concerns may spill over to LED lighting with little supporting evidence.

A recent study (Chang *et al*, 2015) showed that reading from these devices for 4 hours before sleep can suppress and shift the onset of melatonin secretion compared to a print book. The results should be interpreted with care, as a very dim room light condition was used for reading from a print book, rather than a well-directed reading light.

PHE recently looked at potential retinal phototoxicity relating to "blue light" from a range of screens including monitors, laptops, mobile phones, as well as tablets and e-reader similar to those in Chang *et al* (2015).

In the blue light study (O'Hagan *et al*, 2016) the light measured from these devices was shown to be well within long-established international guidelines or safety limits (ICNIRP, 2013).

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Flicker

2016 Human Physiological Responses to Light Meeting Report

. Existing research has addressed the fear of optical damage from LED light, assuring that short periods of direct LED light exposure would not harm the eye, however, additional work is needed to determine if prolonged exposure to LED light can cause problems.

David Sliney of the Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, spoke broadly on retinal phototoxicity, and more directly toward the "blue-light hazard." He explained that phototoxicity occurs when individual photons alter biologically critical molecules in the retina. Photomaculopathy is blue-light retinal phototoxicity that results from a person staring at an intense light source for a long time. Sliney claims that it is difficult to receive this type of injury from LEDs because the eye has a natural aversion and involuntary eye movement to harsh light. However, more research is needed to determine whether there are issues related to chronic exposure to blue light.

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Flicker

2016 Human Physiological Responses to Light Meeting Report

. Existing research has addressed the fear of optical damage from LED light, assuring that short periods of direct LED light exposure would not harm the eye, however, additional work is needed to determine if prolonged exposure to LED light can cause problems.

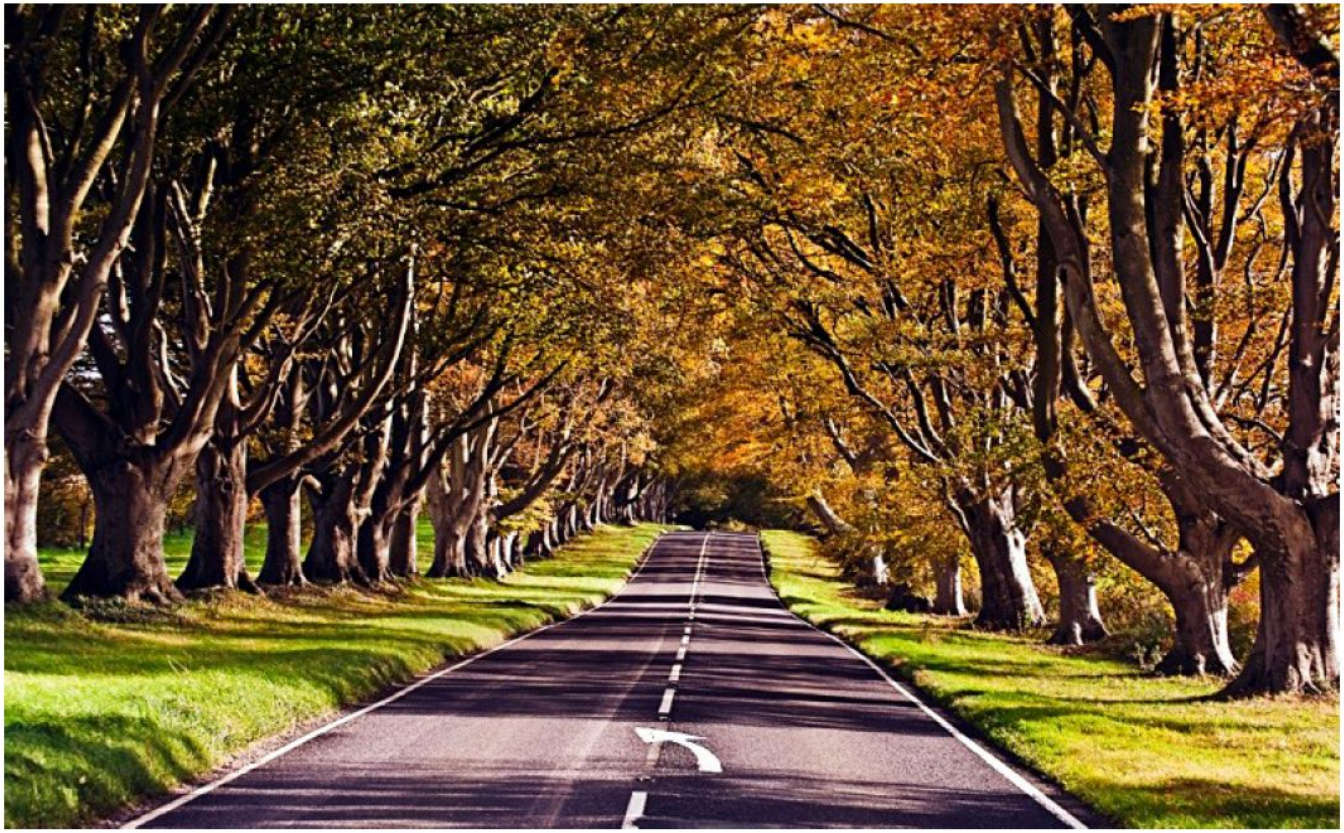
David Sliney of the Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, spoke broadly on retinal phototoxicity, and more directly toward the "blue-light hazard." He explained that phototoxicity occurs when individual photons alter biologically critical molecules in the retina. Photomaculopathy is blue-light retinal phototoxicity that results from a person staring at an intense light source for a long time. Sliney claims that it is difficult to receive this type of injury from LEDs because the eye has a natural aversion and involuntary eye movement to harsh light. However, more research is needed to determine whether there are issues related to chronic exposure to blue light.

FLICKER

Flicker comes in numerous forms, some I am going to touch on are;

- Naturally Occurring
- Tunnel lighting – Avoiding Flicker
- Wagon Wheel effect

Flicker – Natural exposure



Naturally occurring flicker

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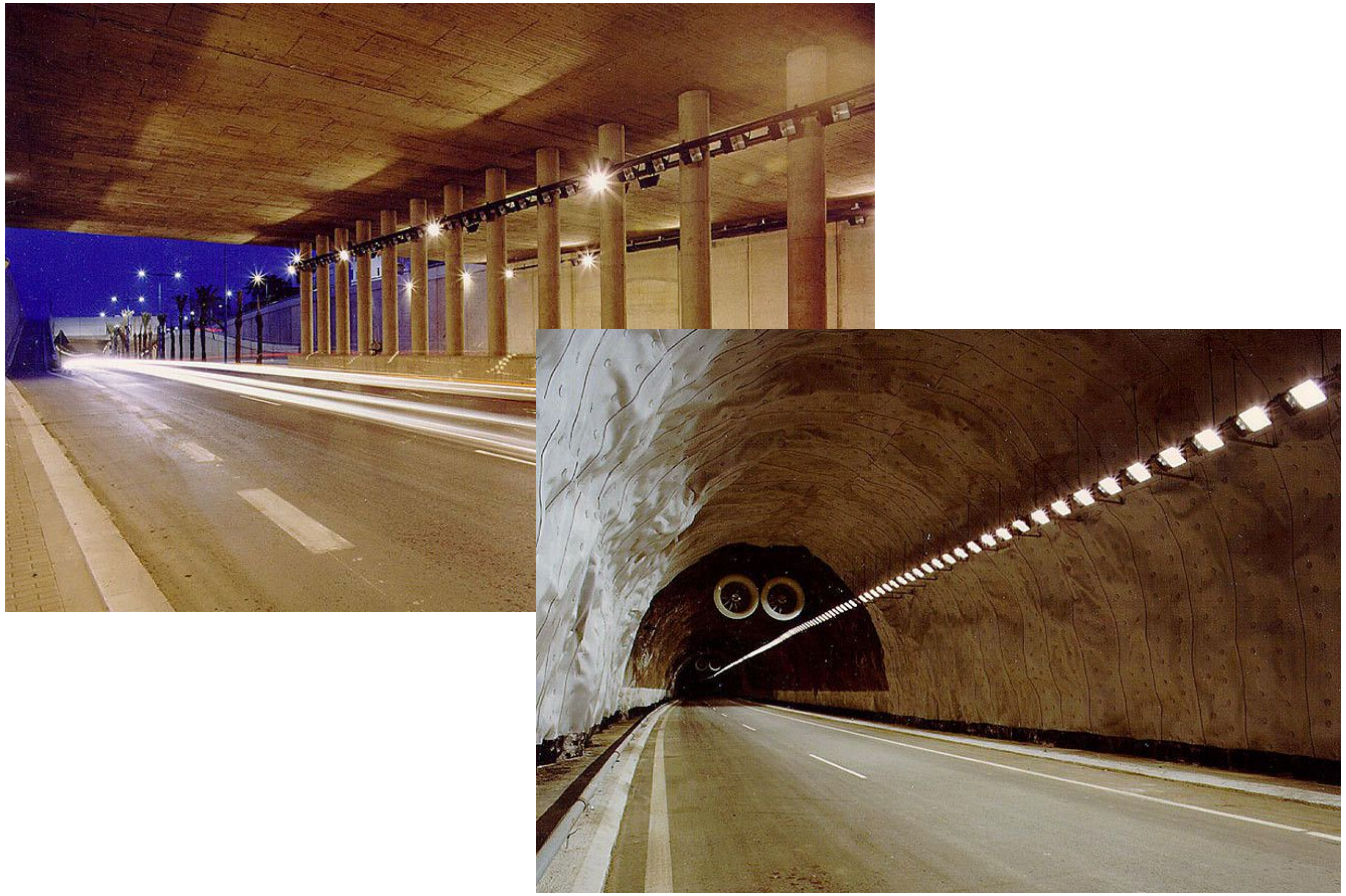
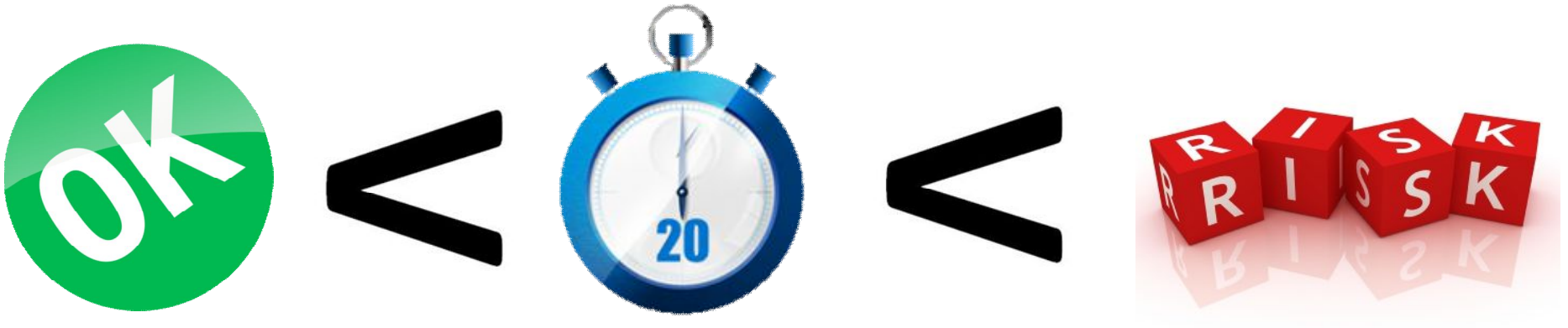
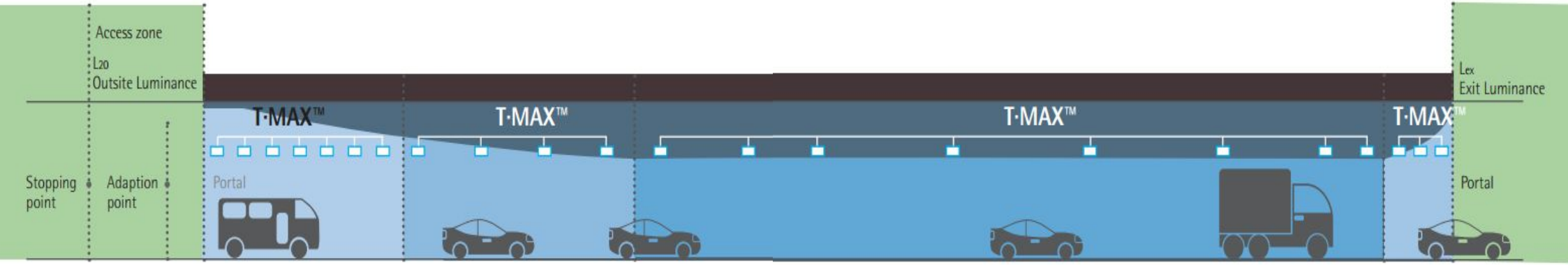


Manual Occurring flicker

BS5489-2-2003 – Flicker – Tunnel Lighting

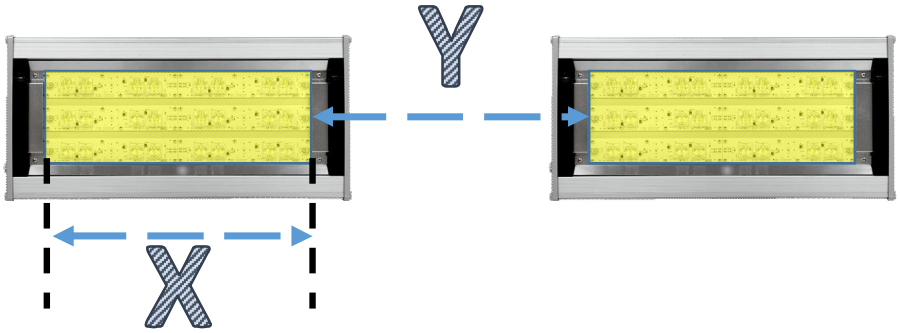




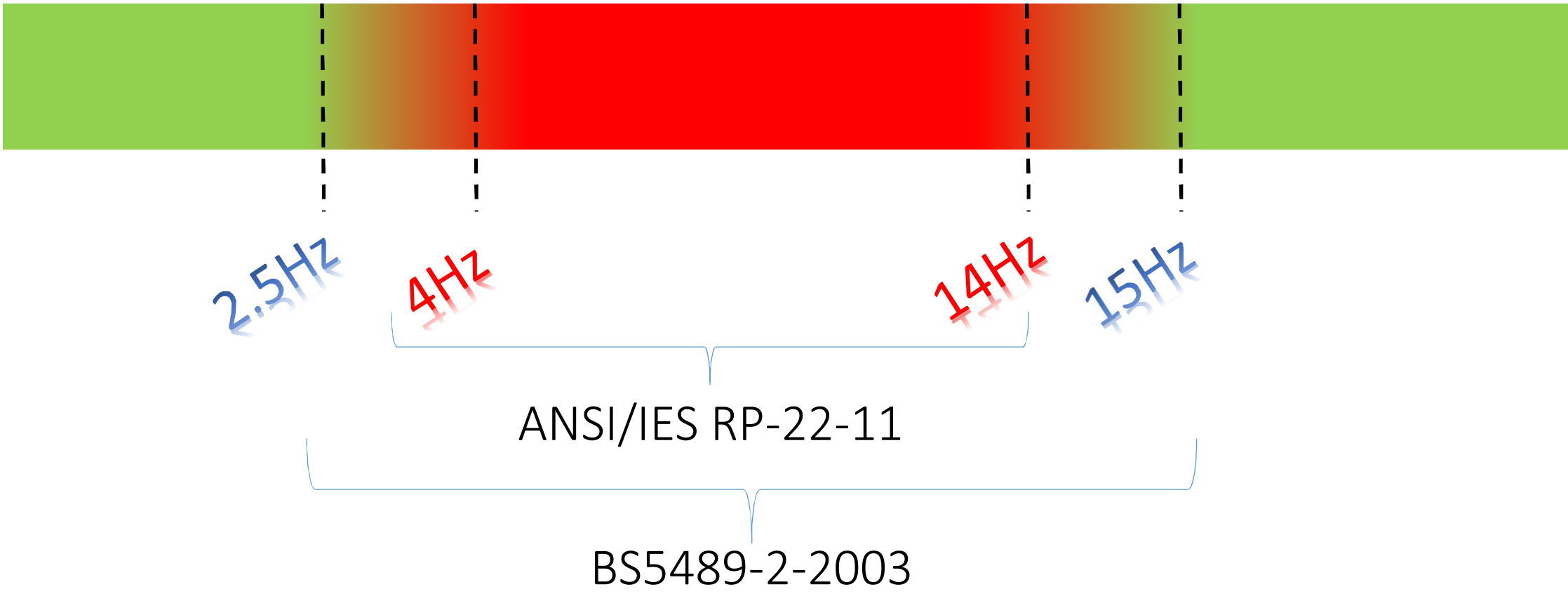
BS5489-2-2003 – Flicker – Tunnel Lighting

$Y < X$

$X < Y$

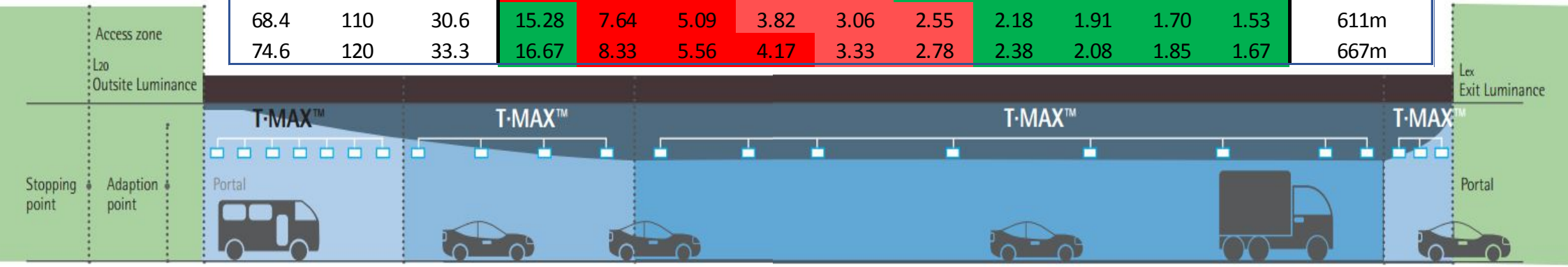


BS5489-2-2003 – Flicker – Tunnel Lighting



BS5489-2-2003 – Flicker – Tunnel Lighting

MPH	km/h	m/s	Spacing (m) 2	4	6	8	10	12	14	16	18	20	Tunnel length after 20s
6.2	10	2.8	1.39	0.69	0.46	0.35	0.28	0.23	0.20	0.17	0.15	0.14	56m
12.4	20	5.6	2.78	1.39	0.93	0.69	0.56	0.46	0.40	0.35	0.31	0.28	111m
18.6	30	8.3	4.17	2.08	1.39	1.04	0.83	0.69	0.60	0.52	0.46	0.42	167m
24.9	40	11.1	5.56	2.78	1.85	1.39	1.11	0.93	0.79	0.69	0.62	0.56	222m
31.1	50	13.9	6.94	3.47	2.31	1.74	1.39	1.16	0.99	0.87	0.77	0.69	278m
37.3	60	16.7	8.33	4.17	2.78	2.08	1.67	1.39	1.19	1.04	0.93	0.83	333m
43.5	70	19.4	9.72	4.86	3.24	2.43	1.94	1.62	1.39	1.22	1.08	0.97	389m
49.7	80	22.2	11.11	5.56	3.70	2.78	2.22	1.85	1.59	1.39	1.23	1.11	444m
55.9	90	25.0	12.50	6.25	4.17	3.13	2.50	2.08	1.79	1.56	1.39	1.25	500m
62.1	100	27.8	13.89	6.94	4.63	3.47	2.78	2.31	1.98	1.74	1.54	1.39	556m
68.4	110	30.6	15.28	7.64	5.09	3.82	3.06	2.55	2.18	1.91	1.70	1.53	611m
74.6	120	33.3	16.67	8.33	5.56	4.17	3.33	2.78	2.38	2.08	1.85	1.67	667m



Flicker – Wagon Wheel Effect

Most often seen in Western movies.
Recordings of any regularly spoked wheel will show it

The effect is a result of temporal aliasing.

It can also commonly be seen when a rotating wheel is illuminated by flickering light.

These forms of the effect are known as stroboscopic effects: the original smooth rotation of the wheel is visible only intermittently.

Flicker – Wagon Wheel Effect

Frame rate of Camera matching blade rotation

Flicker – Wagon Wheel Effect

Links describing Wagon Wheel effect

http://www.mekanizmalar.com/wagon-wheel-effect.html

https://www.youtube.com/watch?v=SFbINinFsxk

https://www.youtube.com/watch?v=QOwzkND_ooU

https://www.youtube.com/watch?v=at38hbbMn7E

https://www.youtube.com/watch?v=MqLwgisyjjw

Flicker – Wagon Wheel Effect

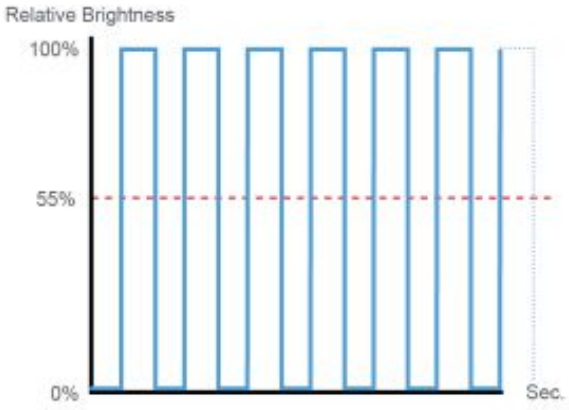
Stroboscope….

Flicker – Wagon Wheel Effect

All Very nice….

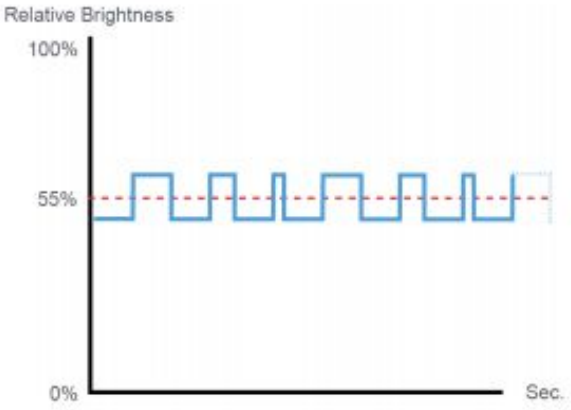
Flicker - Dimming

Methods of Dimming – to 55% examples…..



PWM

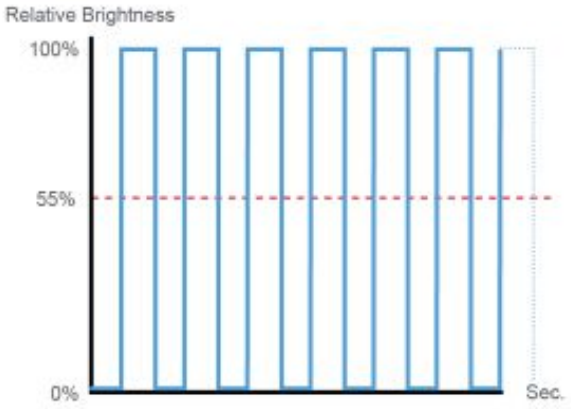
Constant current



Combi Dim

FLICKER

Methods of Dimming – to 55% examples…..

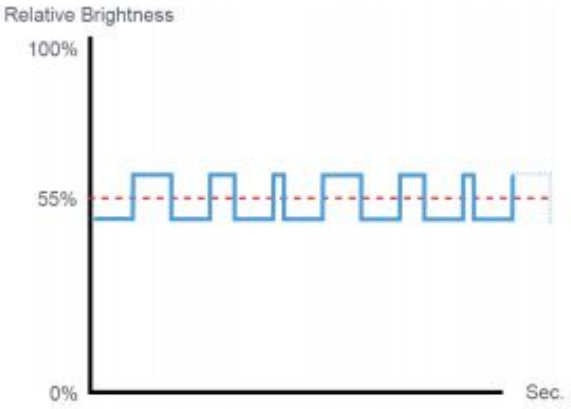


PWM

- Switching LED on/off in fixed frequency
- ✓ Good dimming regulations at low levels
- X Potential noise generation
- X Potentially undesirable flicker, depending on frequency

Constant current

- Varying LED current, LED always on
- ✓ No flicker
- ✓ No noise generation
- ✓ Higher LED efficacy at lower dimming levels
- X Poor dimming regulation at deep dimming (low current)



Combi Dim

- LED are not switched off (amplitude change)
- Modulation in *variable* frequency
- Less current when possible
- ✓ Best dimming regulations at deep dimming levels
- ✓ High duty cycle frequencies
  - ✓ No flicker

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Public Health England

Protecting and improving the nation's health

The Society of Light and Lighting

CIBSE

CRCE-RDD 01-2016

Human responses to lighting based on LED lighting solutions

Commissioned by the Chartered Institution of Building Services Engineers and the Society of Light and Lighting

Public Health England

Protecting and improving the nation's health

Protect and improve health and wellbeing, and reduce health inequalities.

PHE is an executive agency, sponsored by the Department of Health

This report concerns Human responses to lighting based on LED lighting solutions and has been produced by Public Health England (PHE) for the Chartered Institution of Building Services Engineers, CIBSE and the specialist professional body for lighting, the society of light and lighting (SLL)

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Flicker

Public Health England
Protecting and improving the nation's health

Of the Street light fittings that were tested – flicker was not a major issue.

Though it has been in the past

The Society of Light and Lighting

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Flicker

Public Health England
Protecting and improving the nation's health

Flicker

Photo-induced Epilepsy
3-30Hz (can go up to 60 Hz)

Flicker Fusion Frequency
80Hz (assumed Max)

Annoying, Headaches, Eyestrain
Up to about 100Hz – maybe higher

Other Effects (non – specific adverse health effects
Up to 1 kHz

The Society of Light and Lighting

Percentage Flicker

The most widely quoted measure of the amount of flicker in the light given off from lamps. It should be given along with the flicker frequency.

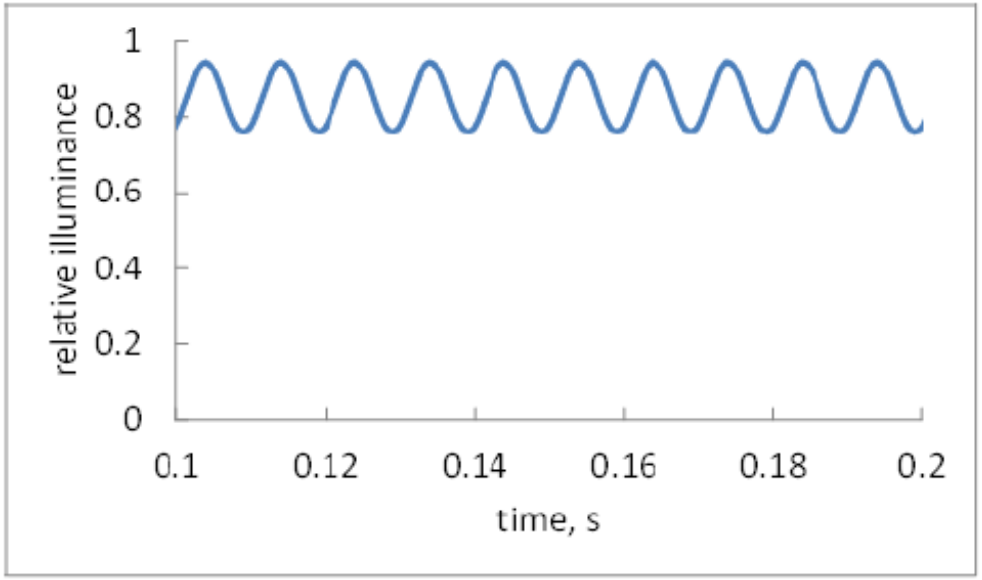
Example;

- Ten cycles in 0.1s
- Curve Smooth (sinusoidal)
- Max illuminance ~0.95
- Min illuminance ~0.75

0.01s > 1/0.01 = 100 Hz (x2 UK 7& Ireland mains freq)

Percentage flicker =

100% x ((0.95 - 0.75) ÷ (0.95 + 0.75)) = 11.8%



Percentage Flicker

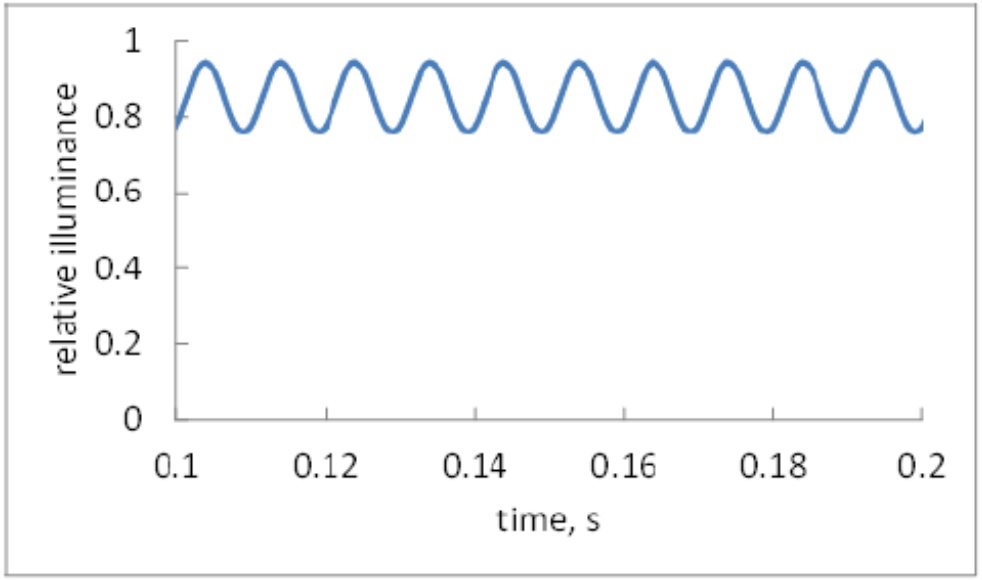
The incandescent , and Tungsten Halogen lamps have Percent Flicker between 9.6% and 12.4%

Public Health England

Protecting and improving the nation's health

use 15% as a rule of thumb figure for new technology.

i.e. no worse then old technology



Flicker Index

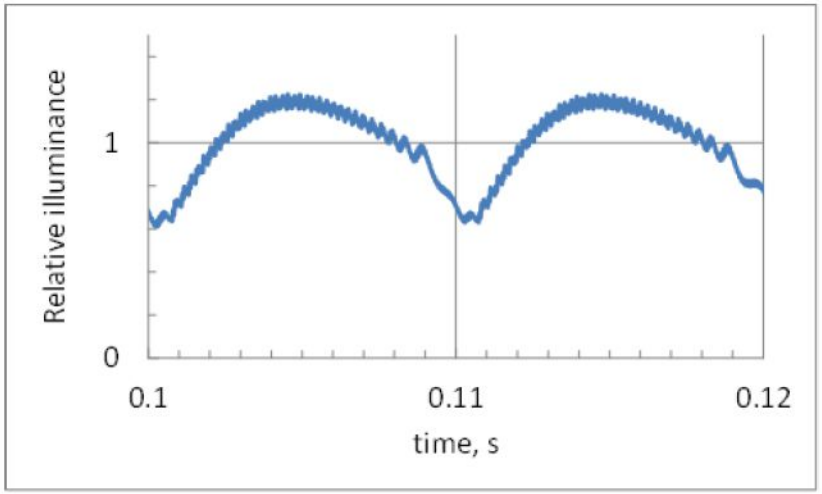
Flicker Metrics

Not really aimed at adverse health effects

Flicker index

Flicker index is calculated as the difference of the area above divided by the sum of the areas above and below the average relative illuminance

Example, flicker index = 0.072



	100Hz	1kHz Smoothed
Percent Flicker	12.7%	2.6%
Flicker index	2.1%	0.4%
Percent Flicker	23.4%	1.2%
Flicker index	2.0%	0.2%
Percent Flicker	17.3%	1.0%
Flicker index	5.1%	0.2%
Percent Flicker	7.8%	0.4%
Flicker index	2.0%	0.1%
Percent Flicker	10.7%	2.5%
Flicker index	2.7%	0.2%

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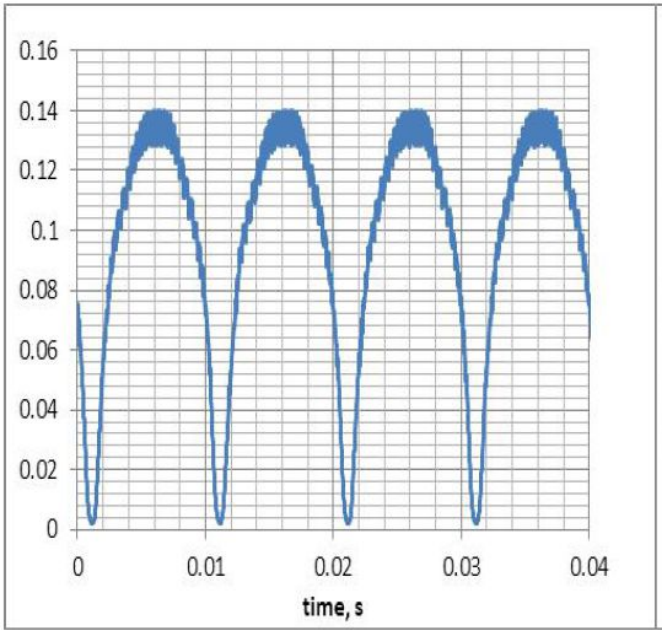
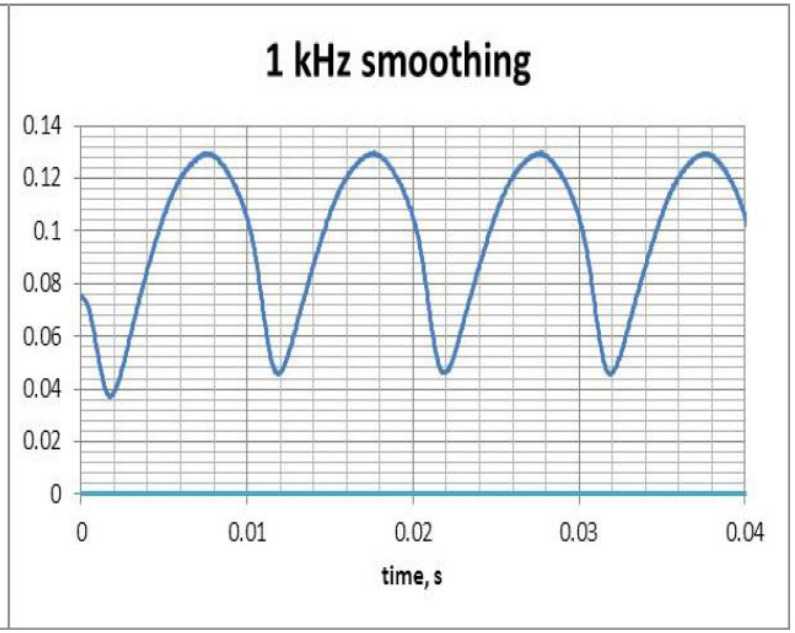
Flicker – Domestic LEDs





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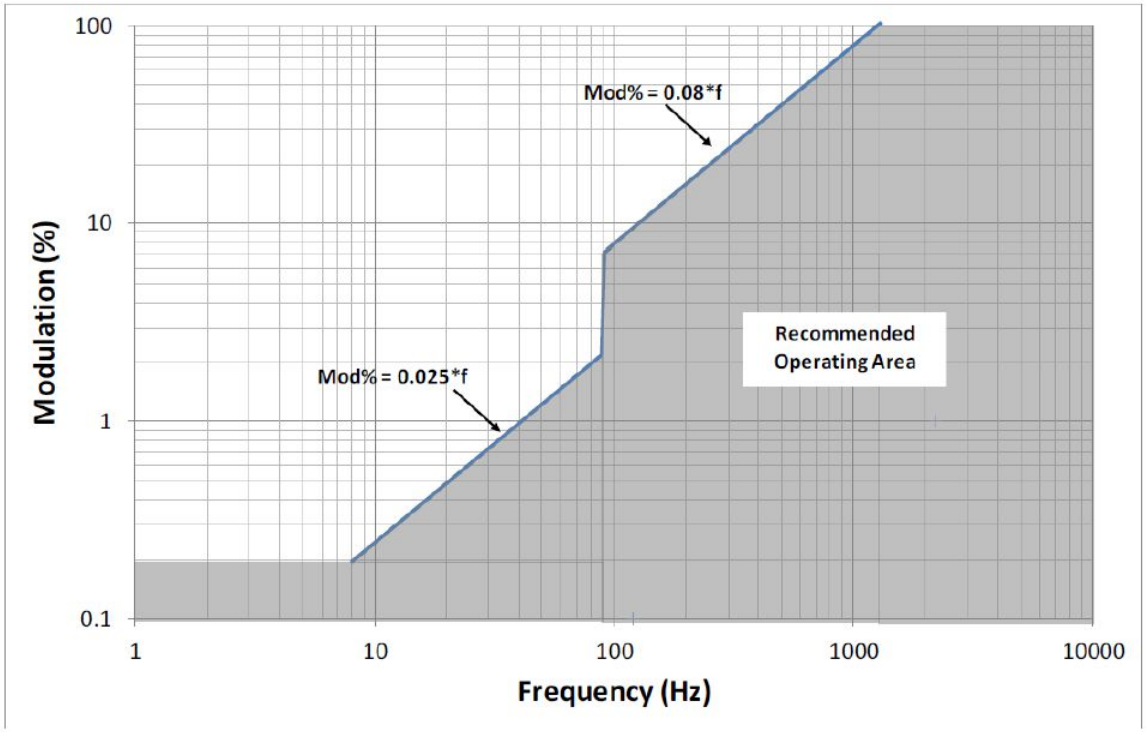
IEEE

IEEE Std 1789-2015
IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers



Summary *(information sources)*

- Nature – *SLL - Lighting Guide 6*
- Overview of Light effects – *IESNA Handbook*
- Direct responses to Light / Perceived Light – *IESNA Handbook*
- Light Colour - *securedbydesign.com – ILP PLG03 – BS5489-1*
- Blue Light Hazard – *SLL - PHE 'Human responses to LED'*
- Flicker – *BS5489-2 – RP-22 - SLL - PHE 'Human responses to LED'*

END

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Sky glow

Indirect - Human Response to Light

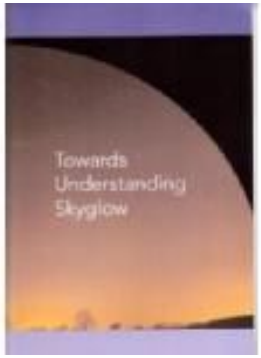
When ever we put lighting outside, some light is going to go to places we don't want it to go.

18% of the terrestrial surface of he earth is exposed to night sky brightness that is considered "polluted" by astronomical standards.

Lower angle light

Lower light levels

Maybe less wavelengths of light.



Appendix 4: Artificial lighting and its effect on animal and plant ecology

Sources of ecological light pollution include sky glow, lit buildings and towers, street lights, sports floodlighting, security measures, etc. It can also be caused by offshore fishing boats, bridges across rivers and estuaries and glare from oil platforms.

The effect of lighting on the natural environment can be difficult to quantify but when there are habitats rich in wildlife near lighting installations there is a possibility that lighting will have adverse effects on insects, animals and plants in the area.

A4.1 Sky luminance

Direct upward light reacts with and is diffused through cloud, mist and airborne particles (Figure A4.1). Note that these particles can often be natural in origin, such as pollen, dust from fields, rain, mist, etc. The area affected and the brightness are dependent on the presence and quantity of diffusing elements and the level of light being distributed by the source (luminaire).

Figure A4.1 Sky glow above a small city in Hampshire (photograph courtesy of Alan Tulla Lighting)

Light pollution is a global issue, with over 18% of the terrestrial surface of the earth exposed to night sky brightness that is considered to be polluted by astronomical standards.

A4.2 Lamp spectra

It is common for ecologists to measure light in terms of lux, which is readily understood by lighting designers and engineers. However, this ignores the biologically important information relating to the light source. A high-pressure sodium lamp may produce the same illuminance as a low-pressure sodium source but the latter contains less UV, which has been shown to attract moths and flying insects. As research continues in this field it will become essential to show measurements of radiation and spectrum-based information relevant to the organisms being discussed, in addition to the actual level of illumination. As a general rule, white light disturbs creatures more than monochromatic or narrow waveband sources.

A4.3 Effects on behaviour and population

Ecological light pollution has been shown to adversely affect behaviour and population of organisms in natural surroundings. These effects are shown in terms of changes in orientation, disorientation or mis-orientation, and attraction or repulsion from the altered lit environment, which may affect foraging, reproduction, migration and communication.

Orientation and disorientation are responses to ambient illumination (the amount of light incident on an object or building), whereas attraction or repulsion have been demonstrated to occur as a response to the intensity of the light source.